ECONOMIC ANALYSIS OF PACKAGING SYSTEMS

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ABSTRACT

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Packaging has a significant impact on the efficiency and effectiveness of the supply chain, where improvement can be achieved through the development and selection of an appropriate packaging system. One way to explore this is through the development and use of mathematical models that facilitate economic analysis of packaging systems. Recently, one of the most remarkable trends in logistics is the extensive use of returnable or reusable containers. Returnable container systems have increasingly been introduced in various industries to take advantages of cost savings, but it is very crucial to ensure that a reusable packaging system is an economical packaging choice. In this thesis, an extensive study of an economic analysis of disposable, recyclable, and reusable packaging systems is conducted. This includes identification of significant cost factors and variables involved in the management of disposable, recyclable and reusable packaging systems, and formulation of a mathematical model to compare total cost of packaging systems. The developed mathematical model can be used to choose the most economical packaging system for industries. The linear programming (LP) method is used to develop the mathematical model. The various new factors such as the collapsible ratio of recyclable, disposable and reusable packages have been introduced for the first time in the economic analysis of the packaging systems. The developed mathematical model can be used for a range of industries and for different industry scenarios. The packaging system information of Toyota assembly plant is used for the validation of a mathematical model. The obtained

results are compared with previous research based on the same data set and results found in concert with the finding of previous research which validate the model.

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CHAPTER 1. INTRODUCTION

1.1. Background

Packaging is all around us and is part of the daily life of consumers and manufacturers. Packaging is essential for protection of the inside products during transit and storage. Every product that manufactured is required to be packed before shipment to the customer. Packaging is used in a wide range of industries and various industrial sectors such as food and drink, healthcare, cosmetics, and consumer goods. Packaging is becoming important field as its usage is growing broadly in line with the global economy. According to a World Packaging Organization (WPO) report, shown in Figure 1.1, the global packaging industry turned over around $563.9 billion in 2009 which includes packaging container sales and packaging machinery sales. This indicates the importance of packaging in supply chain and significance of the study of various packaging options. The main function of packaging is the protection of inside products, but it also facilitates with increasing supply chain efficiency by grouping small products, barrier protection, information transmission, marketing, security, convenience, portion control, etc.

The two types of packaging systems used in industries are expendable and reusable packaging systems. The choice of adopting any packaging system depends upon various parameters such as type of product delivered, packaging requirements, purpose of packaging, and criteria used for the selection of packaging system. The proper choice of packaging system may leads to significant benefits of cost saving and also helps to improve the environmental aspects.

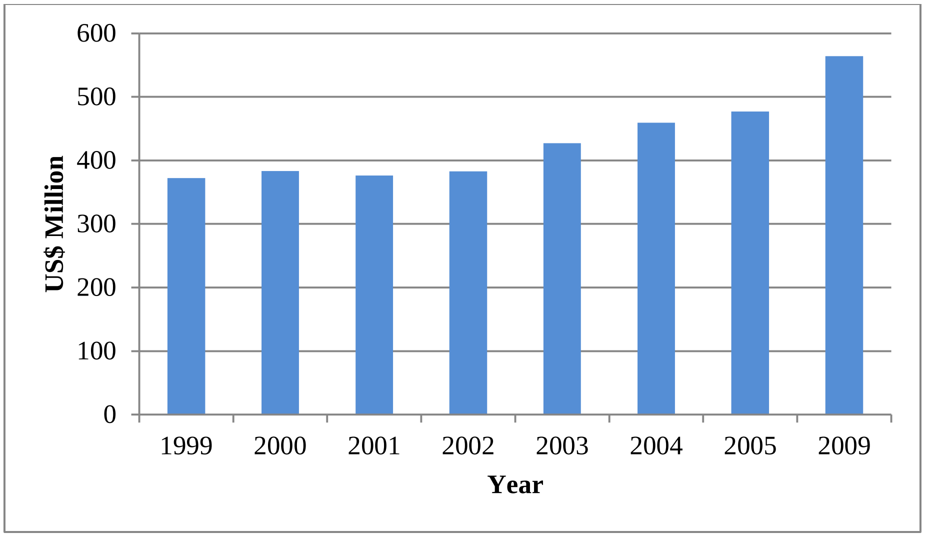

Figure 1.1. The global packaging market, 1999-2009 (Pearson, 2009)

In 1970s, due to outsourcing trends and the results of mergers and acquisitions the manufacturing industry experienced major changes (Ackerholt and Hartford, 2001). The companies who were manufacturing the entire production started outsourcing some of their operations and components from various suppliers and subcontractors. Due to this, the original manufacturer gets several benefits of cost saving, cost restructuring, operational expertise, access to talent pool, reduce time-to market, risk management, and enhanced asset utilization. Subsequently, the original manufacturers started focusing on resources, research and development activities, marketing, and sales functions. These rapid changes within industry structure had great impacts on the logistical flow of material within and outside the industries. The major change observed in a logistics flow was frequent travel of material (raw and in process) during manufacturing and assembly process. The frequently shipment of products and components incorporates with the additional cost of packaging and shipping. Consequently, the main challenge for industries and researchers was to reduce the logistic cost by offering economical packaging options and developing alternative packaging and logistics methods.

Traditionally, the main focus of logistical packaging in all industries was the implementation of one-way or disposable packaging systems (Rosenau et al., 1996; Ackerholt and Hartford, 2001). However, it has been recognized and accepted that expendable packages are not the most economical in all cases because purchase and disposal costs for expendable packages is substantial, especially for products that regularly shipped in larger volumes (Rosenau et al, 1996; Ackerholt and Hartford, 2001). This situation underwent thinking for some alternative packaging and transportation systems.

Recently, study of various packaging systems becomes a significant area for academics and business world. The manufacturers and supply chain companies are focusing more in this field as it offers economic benefits and helps to resolve environmental concern. In order to identify an economical packaging system for any industry it is vital to study and analyze various packaging systems and associated cost factors. The study conducted in this thesis focus on the analysis of expendable and reusable packaging systems and its cost comparison.

1.2. Important Concepts

1.2.1. Supply chain

The Association for Operational Management (APICS) defines supply chain as either, "the processes from the initial raw material to the ultimate consumption of the finished product linking across supplier-users companies," or as, "the function within and outside a company that enable the value chain to make products and provide services to the customer." Figure 1.2 shows classification of supply chain process and its functions at different stages.

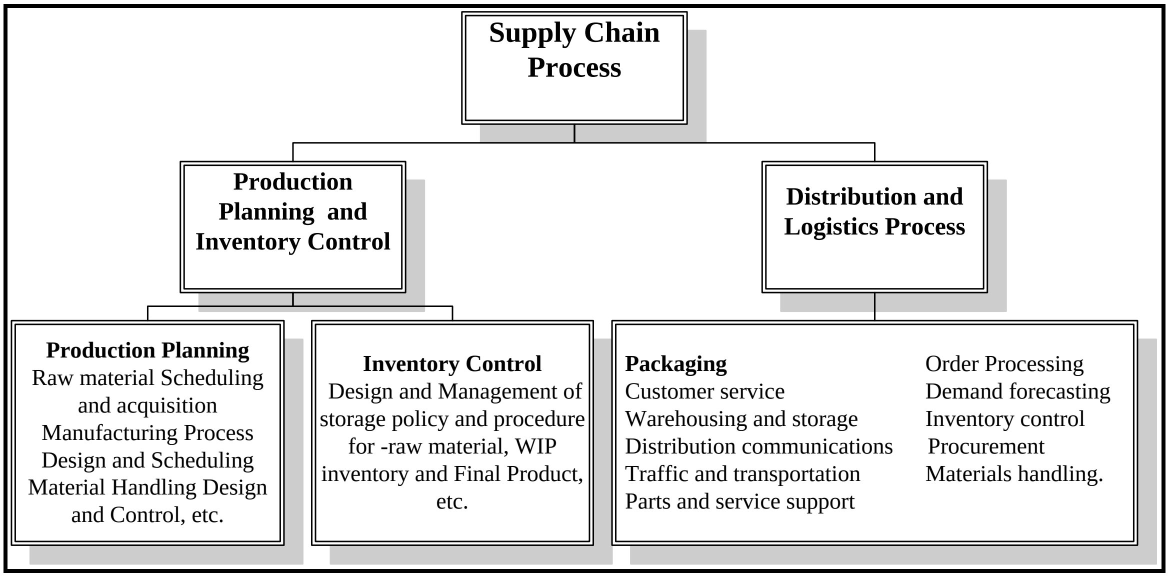

Figure 1.2. The classification of supply chain process and functions

Beamon (1998) defines a supply chain as an integrated process wherein a number of various business entities (i.e. supplier, manufacturer, distributor, and retailer) work together in an effort to acquire raw material, convert raw material into a final product, and deliver final product to retailers. This supply chain consists of forward flow of material and reverse flow of information and is compressed of two basic integrated processes: production planning and inventory control and the distribution and logistics process. The supply chain process explained by Beamon (1998) is shown in Figure 1.3.

1.2.2. Logistics and logistic systems

Few definitions of logistics are discussed that accepted worldwide:

According to the Logistic World, logistics means "having the right thing, at the right place, at the right time."

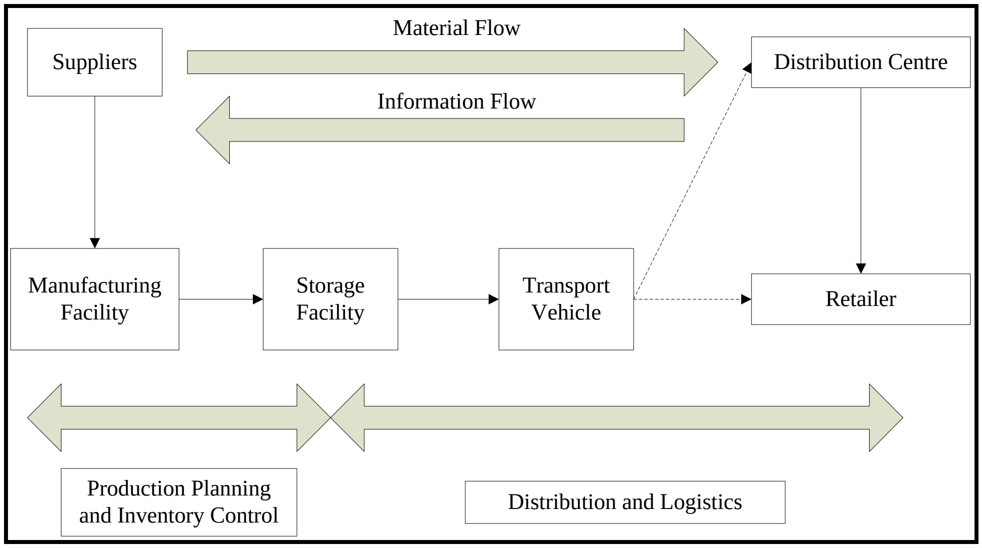

Figure 1.3. The supply chain process (Beamon, 1998)

Lambert and Cooper (2000) and Ackerholt and Hartford (2001) define logistics as the process of planning, implementing, and controlling the efficient, cost-effective flow, and storage of raw materials, in-process inventory, finished goods, and related information from point-of-origin to point of consumption for the purpose of conforming to customer requirements.

From the definitions we can state that the primary objectives of logistics are:

1. To make available the right quantity of right quality products at the right place and right time in the right condition.
2. To offer the best service to consumers.
3. To reduce the cost of operations.
4. To maintain transparency in operations.

According to Paulsson et al. (2000), a supply chain consists of three general flows:

- **The Physical flow** – This includes the flow of goods, packaging, containers, and modes of transportation.

Lumsden (1995) further divides the physical flow into material flow and resource flow. Material flow consists of movements of raw materials, work in process, and finished goods between companies, while, the flow of resources consists of mobile resources.

- Material Flow
- Resource Flow

- **The Information flow** – This consists of flow of information from supplier to consumer and vice versa. The main objective of information flow is to effective and efficient administration of the physical flow.
- **The Financial Flow** – This takes account of the payment to suppliers for the goods and services provided.

1.2.3. Logistic activities

The logistic activities are required to facilitate the flow of product from a point of origin to a point of consumption. The logistic activities divide into three major fields: inbound activities, outbound activities, and activities within operations (Ackerholt and Hartford, 2001). The inbound logistics activities deal with incoming materials from suppliers. The examples of such activities include activities like materials handling, warehousing, inventory control, scheduling, and returns of materials to suppliers. The activities within operations comprise machining, packaging, and assembly operations. Finally, the outbound logistics activities consist of distribution of finished goods, warehousing, materials handling, delivery vehicle operation, and order processing (Porter, 1990). The activities related to packaging takes place throughout the logistics channel and not only within operations. Table 1.1 shows the classification of logistic activities explained by Coyle et al. (1992), Lambert and Stock (1993), and Ackerholt et al. (2001).

Table 1.1. Logistic activities (Lambert and Stock, 1993)

Packaging	Customer service
Plant and warehouse site selection	Distribution communications
Demand forecasting	Traffic and transportation
Procurement	Parts and service support
Warehousing and storage	Materials handling
Inventory control	Return goods handling
Salvage and scrap disposal	Order processing

1.2.4. Packaging

According to the European Union Packaging and Packaging Waste Directive (94/62/EC): "Packaging shall mean all products made of any materials of any nature to be used for the containment, protection, handling, delivery, and presentation of goods, from raw materials to processed goods, from the producer to the user or the consumer."

The packaging is categorized into three main types based on the role of packaging materials:

- **Primary or consumer packaging** – Primary packaging is the material that first envelops the product and holds it. This usually is the smallest unit of distribution or use and is the package which is in direct contact with the contents.

- **Secondary or multi-unit packaging** – Secondary packaging is outside the primary packaging, perhaps used to group primary packages together.
- **Tertiary or transport packaging** – Tertiary packaging is used for bulk handling, warehouse storage, and transport shipping. The most common form is a palletized unit load that packs tightly into containers.

The logistic packaging system is divided into expendable and reusable packaging systems based on number of times the same packaging material is used.

1.2.5. Expendable or one-way packaging

The expendable packaging also known as one-way packaging is intended only for a single transport operation. On the basis of treatment offered to use expendable packaging materials, the expendable packaging system divides into recyclable packaging system and disposable packaging system. Examples of expendable packages include disposable bottles, yogurt containers, food cans, wooden boxes, corrugated board cartons, and disposable pallets.

1.2.6. Reusable or returnable packaging

Unlike expendable packaging, reusable packaging is intended for repeated use, which reduces the volume of packaging material and thus packaging waste. Reusable or returnable packaging is stronger than disposable packaging, as it is exposed to stresses more often. Another requirement placed upon use of reusable packaging system is that should be easy and inexpensive to return, i.e. the packages must be designed such that they are easy to handle and foldable or collapsible. An example of reusable packaging includes returnable bottles, returnable wooden boxes with clip closure, collapsible corrugated boards, beverage crates, and plastic returnable pallets.

1.3. Research Objective

The purpose of this thesis is to develop a mathematical model that could help to make an economical decision about the use of recyclable, disposable, and returnable packaging systems. This model is based on various cost factors related to logistics processes which estimate the total cost of packaging systems and compare their costs to identify an economical packaging option. In order to achieve a better cost estimate, it is essential to identify all the significant cost factors which will affect the company's logistics costs.

The specific objectives of this thesis are:

- To identify and establish the relationship between costs factors to have an overall view of the total cost structure.
- To develop a mathematical model to calculate total cost of recyclable, disposable, and reusable packaging systems.
- To conduct sensitivity analysis to study corresponding cost structure of packaging systems with respect to various input parameters.

CHAPTER 2. LITERATURE REVIEW

2.1. Terminology

Terms used in the literature are almost interchangeable for both types of packaging systems. The first type of packaging system discussed in this thesis is an expendable packaging system. Different terms are used to explain this packaging system includes expendable packaging (Maleki and Meiser, 2010), one-way packaging (Kroon and Vrijens, 1995) and non-returnable packaging (Poll and Schneider, 1995). In the case of expendable packaging system the packaging material after single use is either recycled or disposed. The situation in which expendable packaging material recycled is called a recyclable packaging system. If the expendable packaging material disposed after use is called disposable packaging system. The second type of packaging system widely used and discussed is called a reusable packaging system. Few terms are used, such as reusable packaging (Dubiel, 1996), reusable carriers (Krikke et. al. 2003), and returnable packaging (Kroom and Vrijens, 1995; Buchanan and Abad, 1998). In this thesis the terms recyclable packaging system, disposable packaging system, and reusable packaging system are used.

2.2. Logistic Packaging

Nowadays, the market is becoming ever more demanding as customers are expecting greater product variety, highest quality, enhanced services, and more competitive prices (Garcia-Arca and Prode, 2008). In this context, logistics becomes a key strategic function for the companies to achieve competitive advantages. The proper management of logistics and related activities contributes to the cost reduction and enhanced services. The proper selection of the packaging material and the packaging system helps to manage logistic activities and achieve maximum benefits. Therefore, management of proper logistics and selection of an appropriate packaging system are very important in order to increase the benefits of logistics and packaging. Packforsk (2000) stated that packaging is "the most important component in the distribution chain that is exposed to as many requirements." In 2004, Saghir acknowledged that packaging has a significant impact on the efficiency and effectiveness of supply chain and improvement can be achieved through the adoption and development of packaging and logistics. Packaging also affects supply chain effectiveness as it represents an interface between the supply chain and its customers.

Saghir (2002), defines logistics as "the process of planning, implementing, and controlling the coordinated packaging system of preparing goods for safe, secure, efficient, and effective handling, transport, distribution, storage, retail, consumptions, and recovery, reuse or disposal, and related information combined with maximizing consumer value, sales, and hence profit." This definition combines the functions of logistics (plan, implement, and control) and functions of packaging (contains, protects, secure, promotions, sells, information, and source of profit) together.

In order to gain insight of the packaging systems in the supply chain, it is essential to explore and analyze the packaging related activities. The interaction between packaging, logistics, and marketing are especially important due to trade-offs made when choosing a packaging concept (Prendergast and Pitt, 1996; Saghir, 2004).

The classification of the logistic packaging systems is shown in Figure 2.1. Packforsk (2000) refers to logistical packaging systems as either one-way packaging or reusable packaging. The one-way packaging system is further divided into recyclable and disposable packaging system.

According to Jönsson (1991), logistical packaging systems can be divided under the following categories:

- Packaging types
- Packaging materials
- Combination of packaging type and packaging material

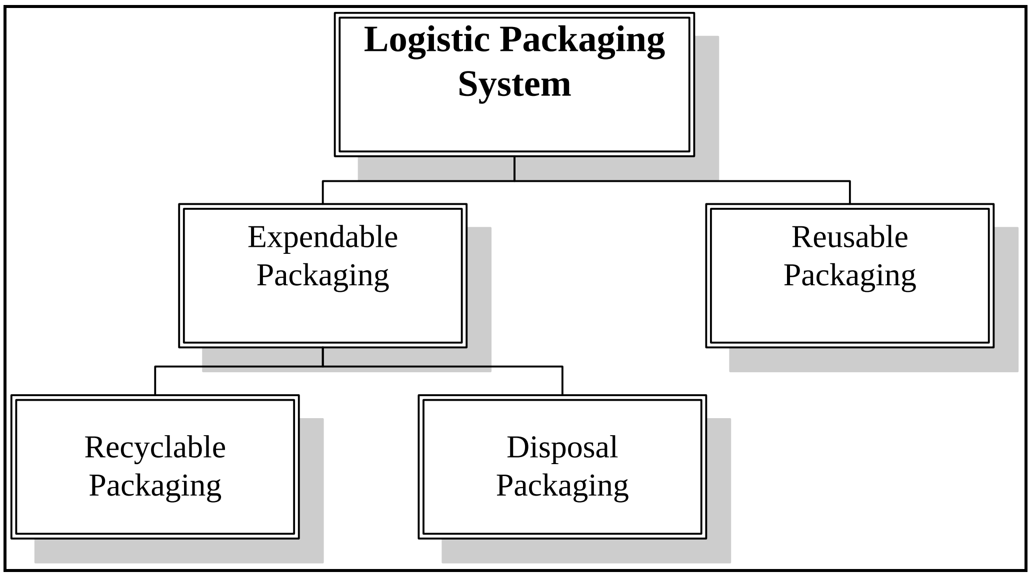

Figure 2.1. Logistic packaging systems

2.3. Logistic Packaging Functions

In order to understand packaging systems, packaging parameters, and effect of packaging parameters on the packaging systems, it is essential to be familiar with the functions of the packaging systems. In 1996, Prendergast et al. described functions of packaging into three major categories. The first function of packaging is related to logistics in which packaging should protect the product in movement during transport and reduce transit damage, spoilage, or loss through theft or misplaced goods. Recently, due to increase in the use of information technology, automation, and advanced material handling has increased the importance of packaging. The selection of proper packaging system contributes to the positive impact on warehouse layout and overall warehouse productivity (Prendergast et al. 1996). The second function of packaging is related to marketing that deals with sales packaging. The purpose of this packaging is to attract the customers' attention and develop positive impression about the product in customers' mind. This function is reinforced when a customer buy products only by looking at packaging appearance (Gray and Guthrie, 1990). The third function of packaging is a combination of both marketing and logistics functions.

In 1990, Robertson described functions of packaging under six categories as containment, protection, apportionment, utilization, convenience, and communication. Meanwhile, Johansson and Westrom (2000) identify six other parameters to analyze the packaging role in logistics. These parameters are product protection, information flow, volume and weight efficiency, right amount and size, handleability, and other value added properties. Chan et al. (2006), combined the functions of packaging explained by Gordan (1990) and Johansson and Westrom (2000) and described functions of packaging as protection, promotion, communication (information flow), convenience (handleability), apportionment (right amount and size), and volume and weight efficiency. Table 2.1 shows functions and characteristics summarized by Chan et al. (2006).

2.4. Expendable or One-way Packaging System

The expendable packaging or one-way packaging system is designed only for a single transport operation. There are several possible reasons for using expendable packaging system which include:

1. The return and reuse of packaging is not economical,
2. The package will not withstand further transport operations, or
3. The packaged item is unique and requires a special customized package.

Table 2.1. Packaging functions and their characteristics (Chan et al., 2006)

Functions	Characteristics
Protection	A fundamental function of packaging is to protect the product from outside environment (e.g., water, moisture, vapor, shock, vibration, compressive forces, etc.), during transporting, and handling. The desired degree of protection is depends on the value and the fragility of the product and its economic justification for nearly absolute protection.
Promotion	Although cartons are considered primarily for the product protection but they also contain features with a sales orientation. Often those products are sold in either a consumer-sized pack or a larger box or case. Some boxes are designed so that they do not have to be unpacked by the stock clerk for stocking on the shelves.
Communication (Information Flow)	The information flow characteristic is not only important in the consumer package, but also in the warehouse and distribution package. There are great costs for handling of incorrect goods, product damaged due to incorrect handling, and reclamation of the secondary and tertiary packages.
Convenience (handleability)	Packaging plays an important role in allowing the handling process in a convenient way. If the packages are deficient in convenience (handleability) function, it would cause workload disorders and product damage due to insufficient instruction for correct handling and result in the rejection of a product by customers.
Apportionment (right amount and size)	Apportionment is essential for consumers by reducing the output from industrial production to a manageable size but it is apt to be overlooked. As the scale of production has increased, it also needs to find effective methods for apportioning the product into the desirable size and amount. If we could not determine the right amount and size of the product in the package, it would tie up our capital and cause the product to be unsalable.
Volume and weight efficiency	With the exception of large, discrete products, all other products must be contained before they can be moved from one place to another. If the volume and weight relation is not designed in an efficient way, there is poor utilization of the distribution chain. This function of packaging is so obvious that it may be overlooked by many parties, but it is the basic function of packaging.

Traditionally, cardboard boxes are used for expendable or one-way packages, but plastic and wood can also be considered as one-way packages if they are discarded after a single use. The corrugated packages are the most used packaging material in the industry due to low cost. In many scenarios corrugated board is an economical option and offers improved product protection. Corrugated packaging material is very easy to modify and lightweight compared to other packaging products. There is real concern about corrugated boxes if a product, shipment method, or destination point is in contact with moisture or rough handling of boxes. The corrugated boxes do not offers adequate protection against moisture and rough handling. On the other hand, wooden and plastic packages offers better protection from moisture and allows rough handling, but they are expensive than corrugated packages.

2.4.1. Types of expendable packaging system

The expendable or one-way packages are designed for single use only and they are either disposed or recycled after use. On the basis of treatment given to packaging material the expendable packaging system is divided into two types:

1. Recyclable Packaging System
2. Disposable Packaging System

In case of a recyclable packaging system, the packages used for logistics are recycled after use. Instead, in case of disposable packaging system the packages are disposed after single use. The decision of selecting disposal packaging system depends upon landfill rates and distance between a manufacturer and a disposal landfill. The rate of landfill varies through ecological areas and is increasing rapidly. In case of recyclable packaging system, the decision of selecting recyclable packaging system depends upon a recycling rate and distance between a manufacturer and recycling center. There are many studies conducted to find economical option for recycling of packaging material and industries are expected to reduce the recycling cost in future.

2.4.2. Advantages of expendable packaging

- Less capital investment
- No return transportation expenses
- No maintenance cost (washing, cleaning, and repair)
- No storage space required for empty packages (as in reusable packaging)

2.4.3. Disadvantages of expendable packaging

- Low product protection
- High damage frequency
- The extra cost required for disposal and recyclable related activities

2.5. Reusable or Returnable Packaging System

The terms reverse logistics and reusable or returnable packagings are sometimes confused or used incorrect ways. However, reusable or returnable packaging is the example of reverse logistics (Kroom and Vrijens, 1995). Reverse logistics refers to the logistics management skills and involved in reduction, management, and disposition of hazardous or non-hazardous waste from packaging and products (Kroom and Vrijens, 1995). Reverse logistics is applied to several stages of logistic chains. The possible areas of application include material management and physical distribution of products. The reuse of packaging material is application of reverse logistics in the area of physical distribution.

Reusable or returnable packaging is type of secondary packaging that can be used more than once in the same system. According to Reusable Packaging Association (RPA), transport packaging must meet four requirements to be considered as "reusable:"

1. The packages are reused for the same or similar application.
2. The packages must be able to meet the original design requirements for at least three consecutive uses (i.e., two reuses).
3. During its useful life the packages are repeatedly recovered, inspected, repaired, and reissued.
4. There is an existing process for recycling or reusing the packages at end-of-life.

The most imperative study about the management of reusable packaging was conducted by Kroon and Vrijens (1995). In which they classified return logistic system into three different groups: switch pool system, system with return logistics, and system without return logistics.

In switch pool system, each participant owns their share of containers. The pool participants are responsible for cleaning, control, maintenance, and storage of containers. A pool participant may be both the sender and recipient, or only acts as senders or recipients of the pool.

In system with return logistics, the containers are owned by central agencies. The agencies are responsible for the return of the containers after they have been emptied by the recipient. A system with return logistics is classified as a transfer system and a depot system.

- Transfer system: In this system, the sender always uses the same containers. The sender is responsible for tracking and tracing of the containers, along with their administration, cleaning, maintenance, and storage.
- Depot system: In this system, the containers are stored at container depot. The containers are cleaned and maintained in the depot and empty containers supplied to senders on demand.

In system without return logistics, the containers are owned by a central agency that rents the container to senders. When senders not use the containers, they are returned to the agency. In this system, the senders are responsible for return logistics, cleaning, control, maintenance, and storage.

2.5.1. Materials used for reusable packaging

There are increasing types of packaging materials that can be used for reusable packages. The commonly used reuse packaging materials includes:

- Pallets (wooden, fiberboard and, plastic)
- Drums and intermediate bulk containers (steel and plastic)
- Crates, boxes, and trays (wooden, fiberboards, and plastic)
- Separators, layer pads, and collars
- Pallet boxes (corrugated board, wood, and plastic)
- Slip sheets and push-pull systems (corrugated board and plastic)
- Metal cages and stillages

2.5.2. Advantages of reusable packaging system

The reusable packaging system offers many advantages over expendable packaging system at all levels of the supply chain. The reusable Packaging Association (RPA) classifies advantages of reusable packaging system into economic, social, and environmental benefits. The same classification is followed by many researchers (Saphire, 1994; Holmes, 1999, NEFAB, 2011). The main advantages of reusable packaging system comprise:

- Economic benefits: The economic benefits of reusable packaging system include reduction of packaging material cost, product damage frequency, labor cost, and inventory cost. It also requires less space for storage and it improves transportation efficiency.
- Social benefits**:** The social benefits of reusable packaging system include improve workplace safety, housekeeping, and workplace efficiency.
- Environmental benefits**:** The environmental benefits of reusable packaging system consists of reduction of packaging waste from entering the solid waste stream, reduction of greenhouse gas emissions, supports source reduction, and requires less energy.

2.5.3. Disadvantages of reusable packaging system

The commonly considered disadvantages of returnable packaging system include:

- Reusable packaging system requires high initial investment
- Extra transportation cost for returns of packages
- Extra cost for tracking, accounting, and cleaning
- Storage space for empty packages

2.6. Expendable Packaging versus Reusable Packaging System

The various authors explain several reasons for increased use of a reusable packaging system over an expendable packaging system but the common reason in all is its significant benefits over a traditional expendable packaging system. These benefit includes better product protection, product security, work environment, material handling, cube utilization, and it reduces the use of expendable packaging materials (Twede and Clarke, 2005; Johansson and Hellstrom, 2007). In addition to all these benefits of a reusable packaging system, several companies learned that returnable packaging can also be commercially rewarding by reducing overall cost (Kroon and Vrijens, 1995).

Twede and Clarke (2004) mentioned two trends in logistics that increased use of a reusable packaging system. The first was in 1980s when just-in-time (JIT) production philosophy was becoming popular. This helps to minimize the inventory replenishment cycle and reduces the number of reusable packages in the system. A JIT strategy also helps to reduce the number of suppliers in the system and reduces the distance between manufacturer and customers. This supports industries to control empty reusable packages and reduce the transport cost. The second trend was in the 1990s of streamlining the supply chain to perform only value added activities in firms.

The decision of adopting an expendable packaging system or reusable packaging system is based on various operating parameters and it also needs a complex supply chain. The success of any packaging system depends on a organization of supply chain, operational factors, cost structure, and performance of packaging system (Twede and Clarke, 2004). In the study sponsored by the corrugated fiberboard industry found that few situations financially favors a returnable packaging system. These situations includes periods of high corrugated box price, short return distance, low backhaul cost, little or no washing containers, long container life, consistent demand, and comparable inbound/outbound payloads (Twede and Clarke, 2004). In 2009, Borocz stated that the environmental regulations of the last few years increased the development of packaging system and it would be favorable for the environment to increase the use reusable packages. The use of reusable packages helps to decrease harmful environmental effects.

There are several studies conducted to identify economical packaging system for various industries. Some important and debatable statements from various authors about reusable packaging system are needed to be discussed. These statements include:

1. The reusable packaging system is more profitable than the expendable packaging system (Davis, 1978; Cheng and Yang, 2005; Brindley, 2006)
2. The reusable packaging system is not always effective in all cases (Kampschroer et al., 1996; Twede and Clarke, 2005)

In order to analyze whether an expendable or a returnable packaging systems is the most rewarding system, number of factors need to be considered. Packforsk (2000) and Hallberg and Uhrbom (2008) stated that transport distance and demand variations are the most important parameters and need to be considered for the analysis of packaging systems. The impact of transportation distance and demand variation in the selection of a packaging system is shown in Figure 2.2. It shows that for long transport distances and high demand variations an expendable packaging system is the most appropriate. This is due to the fact that for returnable packaging system the cost of the return transport of empty returnable packaging would be too high. On the other hand, for short distances and low demand variations a reusable packaging system is appropriate packaging system.

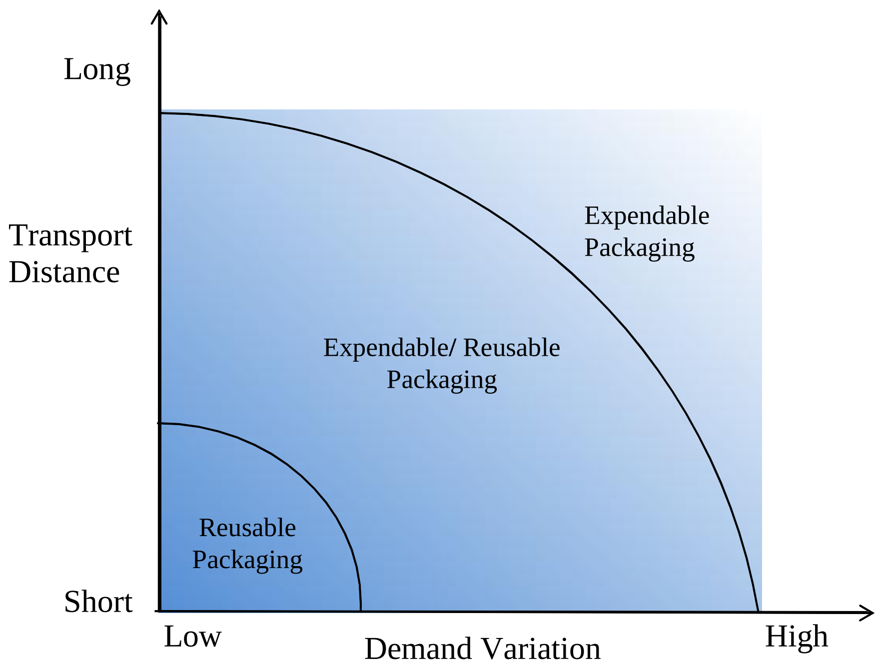

Figure 2.2. Transport distance and demand variation

In order to further analysis of packaging systems it is essential to consider significant factors (Packforsk, 2000; Hallberg and Uhrbom, 2008) which include:

- Tied up capital
- Transport cost
- Return handling cost
- Loss of packaging
- Environmental factors
- Ergonomics benefits

There are number of costs associated with expendable and reusable packaging systems and many authors describe a cost structure from different perceptive. Dubiel (1996) proposed a cost structure of packaging systems in which he considered only costs having a major contribution to the total cost of packaging systems. This cost structure includes packaging material cost, machines cost (appliances and tools), transportation cost, storage cost, buildings cost, packages handling cost, resulting cost (redeliver, repair, settlement of damage, and losses), waste disposal cost, cleaning cost, and labor cost. This study not considered recycling cost required for used components.

In 2003, Kamarthi et al. includes recycling cost of used packaging components that was not considered by any previous research. In his study of evaluation of trade-off in cost and environmental impact of returnable packaging system authors delineates the cost of returnable packaging system into eight elements as: new material cost, manufacturing cost, assembly cost, packages recovery cost, disassembly cost, maintenance cost, recycle cost, and disposal cost.

Twede and Clarke (2005) considered the total cost of packaging system equals an initial investment plus operating cost. The initial investment cost of containers depends upon various operating parameters which include: cycle time, cycle time variation, standardized /specialized containers, numbers of parts shipped during cycle time, and number of parts are fitted in packaging. Similarly, the operating cost depends upon traveling distance (between supplier and manufacturer, supplier and depot), terms of transportation contracts, the relationship between companies, configuration of packaging, number of containers returned at one time (full truck load or LTL) etc. (Twede, 2003; Brindley, 2006). Cheng and Yong (2005) considered total cost of a returnable container system is the addition of transportation cost, labor cost, container cost, and damage cost. The comparison of total cost of expendable and returnable packaging systems shown in Table 2.2 is based on cost structures described by various authors.

Table 2.2. Cost comparison of expendable and returnable packaging

Cost Components	Expendable packaging	Reusable/Returnable Packaging
Capital equipment cost	• Box erectors • Labeling	• Cost of container • Cost of container tracking system • Container washers and sanitizers
Packaging materials cost	• Containers and lids, • Secondary Packaging (bags, pallets, slip sheets, banding, stretch wrap, and dunnage).	• Costs for reusable packaging • Secondary packaging (bags, pallets, slip sheets, banding, stretch wrap, and dunnage)
Packaging storage space cost	• Packaging storage costs such as company-owned and rented warehouse space used.	• Packaging storage costs such as company-owned and rented warehouse space used.
Labor cost	• The loading and unloading cost of packages. • The administrative labor cost of purchasing packaged components.	• The loading and unloading cost of packages. • The administrative labor cost of managing the returnable packaging system.
Product damage cost	• Cost related to product damage, spoilage, or shrinkage due to expendable packaging throughout the supply chain.	• Cost related to product damage, spoilage, or shrinkage due to reusable transport packaging throughout the supply chain.
Shipping cost	• Cost for shipping products from supplier to manufacturer • Cost for shipping empty packages from the manufacturer to disposal landfill or recycling center.	• Cost for shipping products from supplier to manufacturer • Cost for shipping empty packages from manufacturer to again supplier.
Disposal and recycling cost	• Costs associated with disposal of expendable packaging components and secondary packaging, and fees for landfill disposal. • Net revenue from recycling of expendable packages.	• Costs associated with disposal of secondary packaging • Damaged containers beyond repair at the end of their useful life
Maintenance cost	NA	• Container maintenance cost (cleaning, washing, and maintenance) • Cost of missing and damaged containers

2.7. Different Approaches Used for Cost Analysis

The different approaches used by various authors to estimate total cost of expendable and reusable packaging systems meant for different scenarios are discussed. The choice of problem solving approach and tool used is depends on objective function, structure of the supply chain, and availability of data. Davis (1978) used synthetic cost analysis technique to estimate per unit cost for handling fluid milk in a disposable board container and returnable plastic container. Rosenau et al. (1996) compared different cost evaluating methods such as payback period, accounting rate of returns (ARR), internal rate of returns (IRR), and net present value (NPV) to calculate reusable container investments. In his study, author concludes that the Net Present Value (NPV) is the preferred technique for assessment of reusable container investment. The other research conducted by Twede (2003) and Brindley (2006) also agreed that Net Profit Value (NPV) is the best technique for evaluation of reusable container investment.

In 2005, Cheng and Yang conducted a simulation study to determine the operating cost benefit of reusable containers over expendable single use containers. In this study, they combined an integrated bisection algorithm and artificial intelligent search algorithm to determine economical container quantity. Afif et al. (2008) conducted study to develop a model for minimize the total flow cost arising from reusable containers. In this study, authors proposed an appropriate resolution method for better understanding of reusable packaging system behaviors. This method can be used for studying related problems like dimensioning or purchasing policy of reusable containers. Castillo and Cochran (1996) developed a model for an optimal configuration of closed system reusable containers for a large scale soft drink manufacturer. In this they combined two operating models: a pair of linear programs (aggregate and disaggregate) and a different equation simulation to structure overall optimization system. The summary of different methodology used by various authors and their objective function is shown in Table 2.3.

Table 2.3. Review of literature: cost of returnable container system

References	Objective/ Common focus	Methodology
Afif et al., (2008)	Optimizes the total cost of transportation between sites and storage.	Linear Programming based on continues time approach
Bendeira, (2009)	Prioritizing and adjusting full container demand and optimize total cost	Integer linear programming with Decision Support System
Brindley, (2006)	Calculate return on investment for reusable packaging	Net Profit Value (NPV)
Castillo and Cochran (1996)	Formulation of an optimal configuration system for reusable containers	Aggregate and disaggregate linear programming and Simulation
Cheng and Yang (2005)	Cost analysis of the system by order completion and determine the economical quantity	Bisectional Algorithm, Artificial Intelligent search algorithm, Simulation
Davis, (1978)	Handling cost of fluid milk in a disposable board container and returnable plastic container	Synthetic cost analysis techniques
Hellstorm and Johansson (2010)	Impact of different control strategy on the management of returnable transport items	Cast study and simulation study
Hoshino et al. (1995)	Maximizing total profit and recycling rate	Goal Programming
Kamarthi et al., (2004)	Evaluation of trade-off in cost and environmental impact	Multiple objective integer linear programming and Analytical Hierarchy Process
Kroom and Vrijens (1994)	Minimizing the total logistics costs	Mixed integer programming model
Rosenau et al. (1996)	Propose a framework for considering the packaging investment decision	Case study analysis approach

CHAPTER 3. METHODOLOGY

Total cost of any packaging system is calculated as the sum of a capital investment cost and an operating cost. The capital investment cost of an expendable packaging system includes the cost of packaging machines such as box erector and labeling machine. In addition, a reusable packaging system comprises packaging material cost as initial investment cost. The operating cost of expendable and reusable packaging systems consists of shipping cost, labor cost, packaging material cost, product damage cost, recycling cost, disposal cost, and maintenance cost.

The various cost factors associated with recyclable, disposable, and reusable packaging systems and their details are discussed in this section:

1. Shipping Cost**:** Shipping cost of an recyclable and disposable packaging systems includes:

   a) Transportation cost required for the shipment of packages from supplier to manufacturer and

   b) Transportation cost required for the shipment of empty packages from a manufacturer to a recycling center or a disposal landfill.

   In the case of a reusable packaging system, the shipping cost includes:

   a) Transportation cost required for shipment of packages from supplier to manufacturer and

   b) Transportation cost required for shipment of empty packages back to supplier.

2. Labor Cost**:** The labor cost of any packaging systems is the addition of labor cost required at various stages within the supply chain. The labor cost of recyclable, disposable, and reusable packaging systems includes cost for the loading of

packages at supplier, unloading of packages at manufacturer, loading of empty packages at manufacturer, and administration cost for management of packaging materials. In this study, we have decided to consider only unique costs and not common costs. The administrative cost required for managing recyclable, disposable, and reusable packages is assumed as the same and hence not considered for economic analysis. The labor cost of expendable and reusable packaging systems is shown in Figure 3.1.

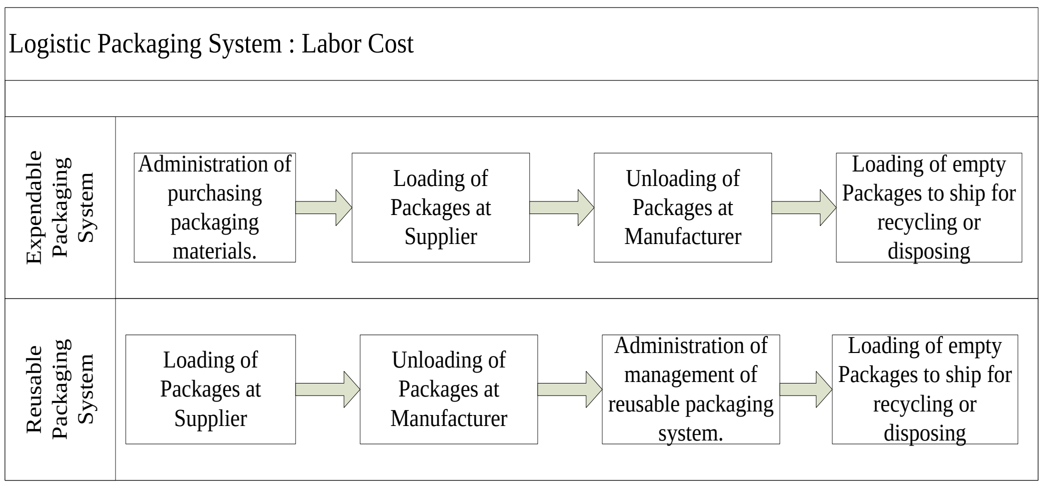

Figure 3.1. Labor costs of various logistics packaging systems

3. Packaging Material Cost**:** The packaging material cost of recyclable and disposable packaging systems includes the cost for packages and secondary packaging components (bags, skids, slip sheets, banding, stretch wrap and dunnage). Similarly, in case of a reusable packaging system, packaging material cost includes costs of reusable packages or containers and secondary packaging components (plastic bags, pallets, slip sheets, banding, wrap, stretch, and dunnage). In economic analysis we assume that total cost of secondary packaging components is the same for all packaging system and hence not considered.

4. Product Damage Cost: The product damage cost of any packaging system is related to the transit damage and spoilage or shrinkage of products throughout the supply chain. The product damage cost is a function of product damage frequency and cost of products inside packages. The damage frequency of packages is depends upon strength of packaging material and packaging design parameters. The product damage frequency of reusable packaging system is always less than product damage frequency of recyclable and disposable packaging system.
5. Recycling Cost**:** The recycling cost is required for recycling of packages after use and is applicable only for recyclable and reusable packaging systems. The recycling cost of packages is varying according to recycling rate per ton and the weight of empty packages. There are two ways to deal with recyclable packages which are:
    a) The manufacturer sells recycling material to recycling companies and obtain revenue and
    b) The manufacturer gives recycling material to recycling company and pays cost required for recycling process. In this case, the manufacturer receives either raw or finished packaging materials.

    For economic analysis study, we considered first option to deal with used packages in which a manufacturer sells packaging material to recycling companies and obtains revenue. In economic analysis this cost is considered as a negative cost as manufacturer receives revenue from recycling of packages. The shipping and labor cost related to handling and shipping are considered in the shipping cost and the labor cost respectively.

6. Disposal Cost: The disposal cost is applicable only for disposable and reusable packaging systems. The disposal cost is associated with disposal of used packages to the landfill. The disposal cost depends upon the landfill rate and weight of used packaging material. The shipping and labor cost related to handling and shipping are considered in shipping cost and labor cost sections respectively.

   In case of a reusable packaging system whether recycling or disposal cost is applicable depends upon the treatment given to reusable packages.

7. Maintenance Cost: The maintenance cost is required for cleaning, washing, and maintenance of reusable packages. In this study, the cost required for repairing of damaged reusable packages and replacement of missing packages is also considered as maintenance cost. The maintenance cost is calculated as a percentage of total packaging material cost.

The costs associated with recyclable, disposable and, reusable packaging systems are shown in Table 3.1.

3.1. Assumptions

The assumptions considered for economic analysis of recyclable, disposable, and reusable packaging system includes:

1. Packaging demand is based on an annual production volume.
2. The dimension and carrying capacity of part-specific containers are uniform across two packaging materials.
3. The manufacturer produces similar line of products
4. Only unique cost factors of all packaging systems are considered for analysis.

Table 3.1. Cost factors of recyclable, disposable and reusable packaging systems

	Packaging System Alternatives		
	Expendable Packaging		Reusable Packaging
Associated Costs	Recyclable	Disposable	
Shipping Cost	√	√	√
Labor Cost	√	√	√
Packaging Material Cost	√	√	√
Product Damage Cost	√	√	√
Recycling Cost	√	NA	√
Disposal Cost	NA	√	√
Maintenance Cost	NA	NA	√

Note: In case of reusable packaging system either reusable or disposal cost is applicable.

3.2. Notations Used for Model

Notations that used for the variables considered in the analysis of packaging systems and are enlisted in Table 3.2.

Table 3.2. The notations used for economic analysis model

Symbol	Description
i	The index for each supplier, where i=1, 2,3… m
j	The index for each parts supplier send, where j=1, 2,3… n
k	The index for each type of package size, where k= 1, 2, 3... p
l	The index used for different truck size, where l=1, 2, 3... q
d	The index used for disposable packaging system
re	The index used for recyclable packaging system
ru	The index used for the reusable packaging system
SC	Shipping cost
LC	Labor cost
PMC	Packaging material cost
PDC	Product damage cost
RC	Recycling cost.
DC	Disposal cost
MC	Maintenance cost
CR	Collapsible ratio
DR	Disposal landfill rate per ton

Table 3.2. The notations used for economic analysis model (Continued)

Symbol	Description
RR	Recycling rate per ton
LR	Labor rate per hour
TR	Transportation rate per mile
PDF	Product damage Frequency
LT	Average loading time for single truck
ULT	Average unloading time for single truck
N_d	Number of trips from manufacturer to disposal landfill
N_i	Number of trips from supplier (i) to manufacturer
N_r	Number of trips from manufacturer to recycling center
T_d	Travel distance from manufacturer to disposal landfill
T_i	Travel distance between supplier (i) to manufacturer
T_r	Travel distance between the manufacturer to the recycling center
DT_{ij}	Dwell time from supplier (i) for product (j) in days
WDP	Weight of disposal packages
WRP	Weight of recycling packages
nu_j	The number of ‘j’ parts required for each product
PC_{jk}	Maximum number ‘j’ parts ‘k’ type of package carry (package capacity).
Prod	Production volume per year
SS	Safety stock of reusable packages.
TC_{kl}	The maximum number of ‘k’ type of packages that ‘l’ type of truck can carry (truck capacity)
L	Life of reusable packages
$REPC_k$	Per unit packaging cost of ‘k’ type of recyclable package
DPC_k	Per unit packaging cost of ‘k’ type of disposable package
$RUPC_k$	Per unit packaging cost of ‘k’ type of reusable package
REP_k	Number of each of ‘k’ type of recyclable package shipping
DP_k	Number of each of ‘k’ type of disposable package shipping
RUP_k	Number of each of ‘k’ type of reusable packages in the system
$REMP_k$	Average cost of material inside ‘k’ type of single recyclable package
DMP_k	Average cost of material inside ‘k’ type of single disposable package
$RUMP_k$	Average cost of material inside ‘k’ type of single reusable package
REW_k	Unit weight of ‘k’ type of recyclable packages
DW_k	Unit weight of ‘k’ type of disposable packages
RUW_k	Unit weight of ‘k’ type of reusable packages
$RUPT_k$	Number of ‘k’ types of reusable packages turns per year

3.3. Shipping Cost

The shipping cost of recyclable, disposable, and reusable packaging systems consists of:

1. Transportation cost for packages shipment from suppliers to manufacturer (Front haul cost) (SC_1)
2. Transportation cost for recyclable packages shipment from a manufacturer to a recycling center (SC_2)
3. Transportation cost for disposable packages shipment from a manufacturer to a disposal landfill (SC_3)
4. Transportation cost for reusable packages shipment back to suppliers. (SC_4)

3.3.1. Suppliers to manufacturer transportation cost (SC₁)

$$SC_1 = \sum_{i=1}^{m}(N_i \times T_i) \times TR \quad (3.1)$$

Where N_i = Number of trucks shipped from supplier 'i' to manufacturer

$$N_i = \sum_{j=1}^{n}\sum_{k=1}^{p}\sum_{l=1}^{q}\left\{\frac{Prod \times nu_j / PC_{jk}}{TC_{kl}}\right\} \quad (3.2)$$

Where, nu_j = Number of 'j' parts required for each product

$Prod$ =Production volume per year

PC_{jk} = Package Capacity of 'j' parts in 'k' type of package

TC_{kl} = Truck Capacity of 'l' type of truck for 'k' type of packages

$\{(Prod \times\ nu_j)\ /PC_{jk}\}$ = Number of packages shipped

T_i = Travel distance from supplier 'i' to manufacturer (in miles)

TR = Transportation rate (per mile)

3.3.2. Manufacturer to recycling center transportation cost (SC₂)

$$SC_2 = \sum_{i=1}^{m}(N_r \times T_r)TR \quad (3.3)$$

Where N_r = Number of trucks shipped from manufacturer to recycling center

$$N_r = CR_{re} \times N_i \tag{3.4}$$

Where, CR_{re} = Collapsible ratio of recyclable packages

T_r= Travel distance from manufacturer to recycling center (in miles)

3.3.3. Manufacturer to disposal landfill transportation cost (SC_3)

$$SC_3 = \sum_{i=1}^{m} (N_d \times T_d) TR \tag{3.5}$$

Where, N_d= Number of trucks shipped from manufacturer to disposal landfill

$$N_d = CR_d \times N_i \tag{3.6}$$

Where, CR_d = Collapsible ratio of disposable packages

T_d= Travel distance from manufacturer to disposal landfill (in miles)

If the same packages are used for the recyclable and disposable packaging system then;

$N_r = N_d$

3.3.4. Manufacturer to suppliers transportation cost (SC_4)

$$SC_4 = \sum_{i=1}^{m} (N_i \times T_i) TR \times CR_{ru} \tag{3.7}$$

Where CR_{ru}= Collapsible ratio of reusable packages

The total shipping costs for all packaging systems is shown in Table 3.3.

Table 3.3. Shipping cost of recyclable, disposable and reusable packaging systems

Packaging System	Shipping Cost	Formula
Recyclable	$(SC)_{re} = SC_1 + SC_2$	$(SC)_{re} = \sum_{i=1}^{m} (N_i \times T_i) TR + \sum_{i=1}^{m} (N_r \times T_r) TR$
Disposable	$(SC)_d = SC_1 + SC_3$	$(SC)_d = \sum_{i=1}^{m} (N_i \times T_i) TR + \sum_{i=1}^{m} (N_d \times T_d) TR$
Reusable	$(SC)_{ru} = SC_1 + SC_4$	$(SC)_{ru} = \sum_{i=1}^{m} (N_i \times T_i) TR + \sum_{i=1}^{m} (CR_{ru} N_i \times T_i)\ TR$

3.4. Labor Cost

The labor cost of recyclable, disposable, and reusable packaging systems is based on:

1. The average time required for loading and unloading of packages
2. Number of packages transported per unit time, and
3. Average labor cost per hour.

The total number of labor hours required for packaging systems is the sum of labor hours required at supplier location and at manufacturer location to perform packaging operations.

The labor hours required at the supplier includes:

- Loading of packages to ship to manufacturer (for all types of packaging systems)
- Unloading of empty reusable packages coming from the manufacturer (only for reusable packaging system)

The total labor at manufacturer includes:

- Unloading of packages received from suppliers (for all types of packaging systems)
- Loading of empty packages to ship to a recycling center (for recyclable packaging system) or a disposal landfill (for disposable packaging system) or back to suppliers (for reusable packaging system).

3.4.1. Labor cost of recyclable packaging system

The labor cost of recyclable packaging system is:

Labor Cost = Total labor hours required in the system X labor rate per hour

Total labor hours required in the system

$$= (\sum_{i=1}^{m} N_i \ X \ LT) + (\sum_{i=1}^{m} N_i \ X \ ULT) + (CR_{re} \ X \ \sum_{i=1}^{m} N_i \ X \ LT)$$

Hence, labor Cost of recyclable packaging system:

$$(LC)_{re} = \{(\sum_{i=1}^{m} N_i \ X \ LT) + (\sum_{i=1}^{m} N_i \ X \ ULT) + (CR_{re} \ X \ \sum_{i=1}^{m} N_i \ X \ LT)\} X \ LR \qquad (3.8)$$

Where, LT = Average time required for loading truck

ULT = Average time required to unload truck

LR = Average labor rate per hour.

3.4.2. Labor cost of disposable packaging system

The labor cost of disposable packaging system is:

Labor Cost = Total labor hours required in the system X labor rate per hour

Total labor hours required in the system

$= (\sum_{i=1}^{m} N_i \ X \ LT) + (\sum_{i=1}^{m} N_i \ X \ ULT) + (CR_d \ X \ \sum_{i=1}^{m} N_i \ X \ LT)$

Hence, labor Cost of disposable packaging system:

$$(LC)_{d} = \{(\sum_{i=1}^{m} N_i \ X \ LT) + (\sum_{i=1}^{m} N_i \ X \ ULT) + (CR_{d} \ X \ \sum_{i=1}^{m} N_i \ X \ LT)\} X \ LR \qquad (3.9)$$

3.4.3. Labor cost of reusable packaging system

The labor cost required for reusable packaging system is,

Labor Cost = Total labor hours required in the system X labor rate per hour

Total labor hours required in the system

$= (\sum_{i=1}^{m} N_i \ X \ LT) + (\sum_{i=1}^{m} N_i \ X \ ULT) + (CR_{ru} \ X \ \sum_{i=1}^{m} N_i \ X \ LT)$

Hence, labor Cost of reusable packaging system:

$$(LC)_{ru} = \{(\sum_{i=1}^{m} N_i \ X \ LT) + (\sum_{i=1}^{m} N_i \ X \ ULT) + (CR_{ru} \ X \ \sum_{i=1}^{m} N_i \ X \ LT)\} X \ LR \qquad (3.10)$$

3.5. Packaging Material Cost

The packaging material cost of recyclable and disposable packaging systems is function of:

1. Number of packages shipped and

2. Average unit cost of recyclable or disposable packages

3.5.1. Packaging material cost of recyclable packaging system

$$(PMC)_{re} = \sum_{k=1}^{p}(REP_k \times REPC_k) \tag{3.11}$$

Where, REP_k = Number of 'k' type of recyclable packages shipped.

$$= \sum_{j=1}^{n}\sum_{k=1}^{p} \{(Prod \times nu_j)/PC_{jk}\}$$

$REPC_k$ = Per unit cost for 'k' type of recyclable package.

3.5.2. Packaging material cost of disposable packaging system

$$(PMC)_d = \sum_{k=1}^{p}(DP_k \times DPC_k) \tag{3.12}$$

Where, DP_k = Number of 'k' type of disposable package shipped.

$$= \sum_{j=1}^{n}\sum_{k=1}^{p} \{(Prod \times nu_j)/PC_{jk}\}$$

DPC_k = Per unit cost for 'k' type of disposable package.

3.5.3. Packaging material cost of reusable packaging system

The packaging material cost of reusable packaging system depends upon:

1. The number of reusable packages in the system
2. Average unit cost of reusable package, and
3. Life of reusable packages.

The Packaging Material Cost of reusable packaging system:

$$(PMC)_{ru} = \sum_{k=1}^{p}(RUP_k \times RUPC_k) \tag{3.13}$$

Where, RUP_k= Number of 'k' type of reusable packages in the system.

$RUPC_k$ = Per unit cost of 'k' type of reusable package.

The number of reusable packages in the system (RP_k) is:

$$RUP_k = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{K=1}^{P}\left\{\frac{\{(Prod \times nu_j)/PC_{jK}\}}{(365/DT_{ij})}\right\} + SS \tag{3.14}$$

Where, DT_{ij}=Dwell time for supplier 'i' and product 'j' (in days)

SS = Safety stock of reusable packages.

The packaging material cost per year can be calculated by dividing equation (3.14) by the life of reusable packaging system. The yearly packaging material cost is considered for comparison of three packaging systems.

3.6. Product Damage Cost

The product damage cost is depends upon product damage frequency and cost of items inside the packages.

3.6.1. Product damage cost of recyclable packaging system

$$(PDC)_{re} = (PDF)_{re} \times \sum_{k=1}^{p} (REP_k \times REMP_k) \quad (3.15)$$

Where, $(PDF)_{re}$ = Damage frequency of recyclable packaging system.

REP_k = Number of 'k' type of recyclable packages shipped.

$REMP_k$ = Average cost of material inside 'k' type of a single recyclable package.

3.6.2. Product damage cost of disposable packaging system

$$(PDC)_{d} = (PDF)_{d} \times \sum_{k=1}^{p} (DP_k \times DMP_k) \quad (3.16)$$

Where, $(PDF)_{d}$ = Damage frequency of a disposable packaging system.

DP_k = Number of 'k' type of disposable package shipped.

DMP_k = Average cost of material inside 'k' type of a single disposable package.

3.6.3. Product damage cost of reusable packaging system

$$(PDC)_{ru} = (PDF)_{ru} \times \sum_{k=1}^{p} (RUPT_k \times RUMP_k) \quad (3.17)$$

Where, $(PDF)_{ru}$ = Damage frequency of reusable packaging system.

$RUPT_k =$ Number of 'k' type of reusable packages turns per year.

$RUMP_k$ = Average cost of material inside 'k' type of single reusable package.

3.7. Recycling Cost

Recycling cost is applicable only for recyclable packaging system and reusable packaging system (if reusable packages are recycled at the end of their life). The recycling cost mainly depends upon recycling rate and weight of recycled packaging material.

3.7.1. Recycling cost of recyclable packaging system

$$RC_{re} = RR \times WRP_{re} \tag{3.18}$$

Where, RR = Average recycling revenue per ton

WRP_{re} = Weight of recyclable packaging material.

$$= \sum_{k=1}^{p}(REP_k \times REW_k)$$

Where, REW_k = Unit weight of 'k' type of recyclable package.

Hence, the recycling revenue of recyclable packaging material is:

$$RC_{re} = RR \times WRP_{re} = RR \times \sum_{k=1}^{p}(REP_k \times REW_k)$$

3.7.2. Recycling cost of reusable packaging system

$$RC_{ru} = RR \times WRP_{ru} \tag{3.19}$$

Where, WRP_{ru} = Weight of reusable packaging material that recycled.

$$\sum_{k=1}^{p}(RUP_k \times RUW_k)$$

Where, RUW_k = Unit weight of 'k' type of reusable package.

Hence, the recycling revenue of recyclable packaging material is:

$$RC_{ru} = RR \times WRP_{ru} = RR \times \sum_{k=1}^{p}(RUP_k \times RUW_k)$$

3.8. Disposal Cost

The disposal cost is applicable only for disposable packaging system and reusable packaging system (if reusable packages are disposed at the end of their life). The disposal cost mainly depends upon landfill rate and weight of disposable packaging material.

3.8.1. Disposal cost of disposable packaging system

$$DC_d = DR \times WDP_d \tag{3.20}$$

Where, DR = Average disposal rate per ton

WDP_d = Weight of disposable packaging material.

$= \sum_{k=1}^{p}(DP_k \times DW_k)$

Hence, the disposal cost of disposable packaging system is:

$$DC_d = DR \times WDP_d = DR \times \sum_{k=1}^{p}(DP_k \times DW_k)$$

3.8.2. Disposal cost of reusable packaging system

$$DC_{ru} = DR \times WDP_{ru} \tag{3.21}$$

Where, DR = Average disposal landfill rate per ton, and

WDP_{ru} = Weight of reusable packaging material that disposed.

$= \sum_{k=1}^{p}(RUP_k \times RUW_k)$

Hence, the disposal cost of reusable packaging system;

$$DC_{ru} = DR \times WDP_{ru} = DR \times \sum_{k=1}^{p}(RUP_k \times RUW_k)$$

3.9. Maintenance Cost

The maintenance cost is only applicable for the reusable packaging system and is considered as a percentage of total cost of packaging materials.

$$MC = \theta \times (PMC)_{ru} \tag{3.22}$$

Where θ = Fraction of total material costs considered as maintenance cost

$(PMC)_{ru}$ = Packaging Material cost of reusable packaging system

3.10. Total Cost

The total cost of recyclable, disposable, and reusable packaging systems is shown in Table 3.4. The total cost of each packaging system is the sum of all the costs of respective columns shown in Table 3.4. The recycling cost showed as negative because manufacturer obtained revenue from the recycling of packages.

Table 3.4. Total cost of packaging systems

	Packaging System Alternatives		
	Expendable Packaging		Reusable Packaging
Associated Costs	Recyclable	Disposable	
Shipping	$\sum_{i=1}^{m}(N_i \times T_i)TR + \sum_{i=1}^{m}(N_r \times T_r)TR$	$\sum_{i=1}^{m}(N_i \times T_i)TR + \sum_{i=1}^{m}(N_d \times T_d)TR$	$\sum_{i=1}^{m}(N_i \times T_i)TR + \sum_{i=1}^{m}(CR_{ru}N_i \times T_i)TR$
Labor	$\left\{(1 + \mathrm{CR_{re}})\sum_{i=1}^{m}\mathrm{N_i\ X\ LT} + \sum_{i=1}^{m}\mathrm{N_i\ \ X\ ULT}\right\}\mathrm{X\ LR}$	$\left\{(1 + \mathrm{CR_{d}})\sum_{i=1}^{m}\mathrm{N_i\ X\ LT} + \sum_{i=1}^{m}\mathrm{N_i\ \ X\ ULT}\right\}\mathrm{X\ LR}$	$\left\{(1 + \mathrm{CR_{ru}})\sum_{i=1}^{m}\mathrm{N_i\ X\ LT} + \sum_{i=1}^{m}\mathrm{N_i\ \ X\ ULT}\right\}\mathrm{X\ LR}$
Material	$\sum_{k=1}^{p}(REP_k \times REPC_k)$	$\sum_{k=1}^{p}(DP_k \times DPC_k)$	$\left\{\sum_{k=1}^{p}(RUP_k \times RUPC_k)\right\}$
Product Damage	$(PDF)_{re} \times \sum_{k=1}^{p}(REP_k \times REMP_k)$	$(PDF)_{d} \times \sum_{k=1}^{p}(DP_k \times DMP_k)$	$(PDF)_{ru} \times \sum_{k=1}^{p}(RUPT_k \times RUMP_k)$
Recycling	$-\left(RR \times \sum_{k=1}^{p}(REP_k \times REW_k)\right)$	NA	$-\left(RR \times \sum_{k=1}^{p}(RUP_k \times RUW_k)\right)$
Disposal	NA	$DR \times \sum_{k=1}^{p}(DP_k \times DW_k)$	$DR \times \sum_{k=1}^{p}(RUP_k \times RUW_k)$
Maintenance	NA	NA	$\theta \times (PMC)_{ru}$

CHAPTER 4. MODEL VALIDATION

The information used for the model validation is obtained from the case study prepared by the council of logistics management with the Toyota Automobile Company. This case study was prepared to help for academic research and based on fictitious data (Goldsby et al. 2000). The data obtained from this case study offers basic information required to illustrate the proposed model.

4.1. Background of Case Study

In late 1988, Toyota Motor Manufacturing Indiana, Inc. (TMMI) started manufacturing Tundra as its first full-size truck. The company discussed fundamental decisions regarding logistics and supply chain operations before starting production. The main decision about logistics and supply chain operations included selection of shipping containers. These containers are used for delivery of parts from suppliers to the Toyota factory. In this study, three packaging systems are considered to identify the most economical packaging option. There are a few assumptions used in this case which include:

- The total container demand and operations cost are based on an annual production volume of 102,000 Tundra trucks. It is assumed that the production of trucks is evenly balanced over the course of Toyota's production year.
- The production year in Toyota covers 51 weeks, five days each week. Thus, the total number of working days is 255.
- The average daily production volume is 400.
- The dimensions and carrying capacity of part specific containers are uniform across the two container options.

- The same packages are being used for the recyclable and disposable packaging systems.
- There is a single type of truck used for container transportation regardless of the container choice.

4.2. Data Used for Model Validation

Goldsby et al. (2000) published a case study report which is based on the Toyota assembly plant. The basic information about the suppliers, manufacturer, and packaging system parameters is acquired from this report. Five key suppliers are considered for the analysis and information about these suppliers is shown in Appendix Table A.1. The information includes list of parts that suppliers sent to the TMMI, number of each parts required for a single truck, type of containers used, carrying capacity of containers, and dwell time for each part from individual suppliers. The company used four different sizes of containers for shipping material from suppliers to the TMMI. The information about container dimensions, weight, per unit cost, and damage frequency is shown in Appendix Table A.2. The additional system input parameters from Toyota report are given in Appendix Table A.3.

There are few new variables that considered in this mathematical model but not part of Toyota case study. The values of such variables are assumed and information about these assumptions is given in Table A.4. The dimension and carrying capacity of standard 20 foot truck is used for calculations of shipping cost.

4.3. Cost Calculations

The shipping cost required to transport parts from supplier to manufacturer is shown in Table 4.1.

Table 4.1. Shipping cost calculations

Supplier	Parts required in one year	Units of Packages rotation per year	Number of trips for each part per year	Number of trips for each supplier per year	Shipping Cost (supplier to manufacture)
Blue grass Industries	408,000	51,000	177	336	84,115
	102,000	20,400	71		
	102,000	20,400	71		
	2,448,000	24,480	17		
Blue Inc.	102,000	12,750	44	398	90,254
	408,000	34,000	354		
Kentucky Industries	102,000	2,040	1	203	45,084
	204,000	34,000	48		
	204,000	17,000	24		
	204,000	34,000	118		
	102,000	3,188	11		
Missouri Industries	408,000	34,000	354	738	187,337
	102,000	25,500	266		
	102,000	25,500	89		
	102,000	5,100	18		
	102,000	8,500	12		
Reeds Inc.	102,000	20,400	213	349	101,465
	102,000	25,500	89		
	204,000	34,000	48		
	Total	431,758	2,026	2,026	508,255

The shipping cost components and total shipping cost of recyclable, disposable, and reusable packaging systems are shown in Table 4.2. The transportation rate of $1.3 per miles is considered for calculations of total shipping cost. The labor cost of recyclable, disposable, and reusable packaging systems is shown in Table 4.3. The total packaging cost of all packaging systems are shown in Table 4.4.

Table 4.2. Shipping cost components and total shipping cost

Shipping cost components	Cost
Suppliers to manufacturer (SC1)	$508,255
Manufacturer to recycling center (SC2)	$13,169
Manufacturer to disposal landfill (SC3)	$13,169
Manufacturer to suppliers (SC4)	$101,651

Total shipping cost	
Recyclable	$521,424
Disposable	$521,424
Returnable	$609,905

Table 4.3. Labor cost

Description	Recyclable	Disposable	Reusable
Time for loading trucks (suppliers)	1,013	1,013	1,013
Time for unloading (manufacturer)	1,013	1,013	1,013
Time for loading trucks (manufacturer)	51	51	203
Time for loading and unloading	2,077	2,077	2,229
Labor cost	$31,149.75	$31,149.75	$33,429.00

Table 4.4. Packaging material cost

Package Type	Number of packages in system		Cost per Unit		Total Cost		
	Recyclable and Disposable	Reusable with safety stock	Recyclable and Disposable	Reusable	Recyclable	Disposable	Reusable
1	26,520	431	$0.29	$29.49	$7,691	$7,691	$12,720
2	93,500	1,553	0.49	44.88	$45,815	$45,815	$69,685
3	1,97,838	3,327	0.66	52.65	$130,573	$130,573	$175,167
4	1,13,900	1,817	2.07	99.69	$235,773	$235,773	$181,116
				Total	$419,852	$419,852	$438,688

It shows that the packaging material cost of recyclable and disposable systems are equal because identical packages are used for recyclable and disposable packaging systems.

In case of reusable packaging system, the packages are either recycled or disposed at the end of the use but in this case study we have not considered recycled and disposed cost associated with reusable packaging system.

The recycling cost, disposal cost, and maintenance cost is shown in Table 4.5. The total cost of recyclable, disposable and reusable packaging systems is calculated by adding respective cost factors as shown in Table 4.6 and in Figure 4.1. The breakdown of total cost of all three packaging systems is shown in Figure 4.2.

Table 4.5. Product damage, recycling, disposal, and maintenance cost

Packaging Type	Product Damage Cost
Recyclable	$1,079,393.75
Disposable	$1,079,393.75
Reusable	$ 863,515.00

Packaging Cost Factor	Cost
Recycling Cost	$ 11,506.34
Disposal Cost	$ 10,975.28
Maintenance Cost	$ 21,934.40

Table 4.6. Total cost of recyclable, disposable, and reusable packaging systems

	Packaging system alternatives		
	Expendable packaging		Reusable packaging
Associated Costs	Recyclable	Disposable	
Shipping Cost	$521,423.50	$521,423.50	$609,905.40
Labor Cost	$31,149.75	$31,149.75	$33,429.00
Packaging Material Cost	$419,851.55	$419,851.55	$146,229.33
Product Damage Cost	$1,079,393.75	$1,079,393.75	$863,515.00
Recycling Cost	$11,506.34	NA	NA
Disposal Cost	NA	$10,975.28	NA
Maintenance Cost	NA	NA	$21,934.40
Total Cost	$2,040,312.21	$2,062,793.83	$1,675,013.13

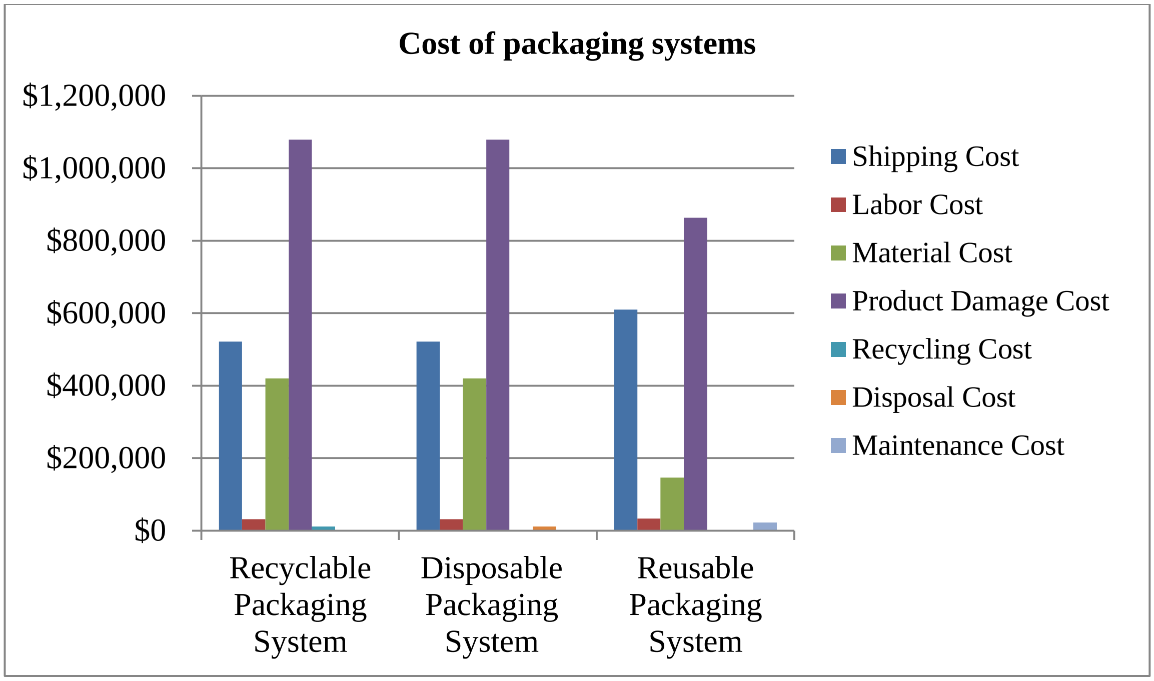

Figure 4.1. Cost of packaging systems

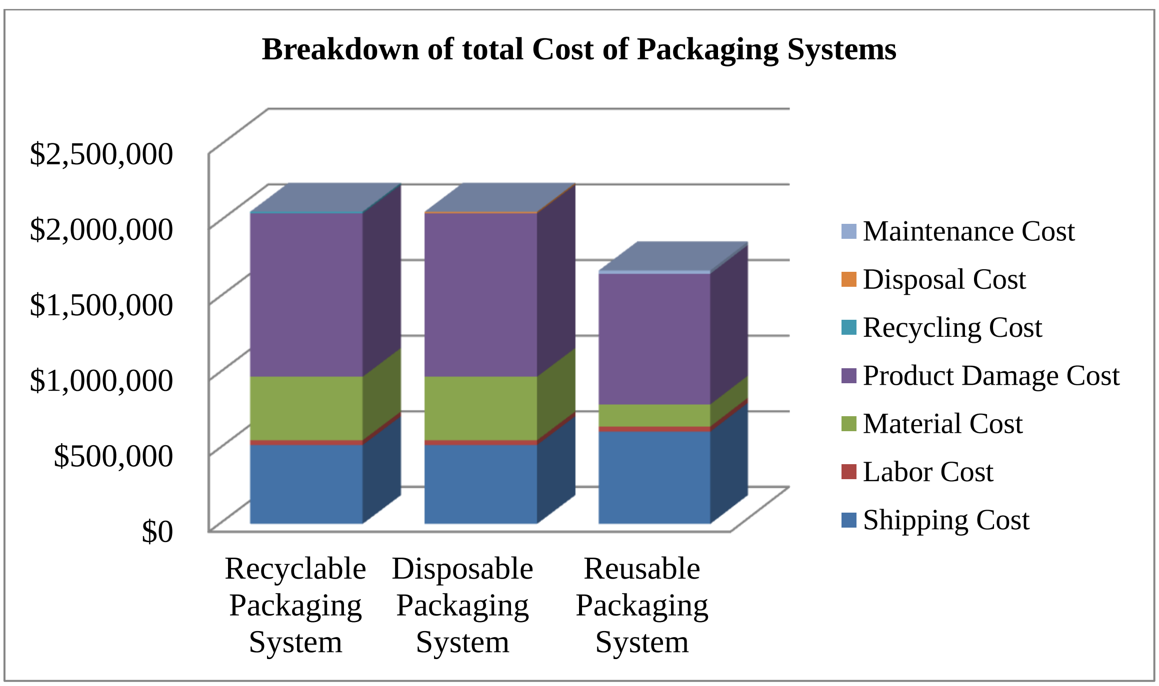

Figure 4.2. Total cost of different packaging systems

4.4. Conclusions

The cost comparison of all three packaging systems concludes that reusable packaging system is the most economical option for Toyota assembly plant. The results obtained from this study are compared with similar study conducted by Yuan and Yang (2005), in which they used the same dataset from Toyota to validate the model. In their research Yuan and Yang (2005) demonstrates that recyclable packaging system is the most economical packaging option for long term use. They used discrete event simulation to support their arguments and used 765 days simulation run. The obtained result is in concert with Yuan and Yang case study results which validate the model.

CHAPTER 5. SENSITIVITY ANALYSIS

Sensitivity analysis is performed to study the behavior of total cost of recyclable, disposable, and reusable packaging system for different values of cost factors and cost variables. It also helps to identify significant cost factors and cost variables which play vital role in decision of an economical packaging system. The scenario considered for sensitivity analysis includes a single supplier, recycling center, and disposal landfill. The important cost factors of recyclable, disposable, and reusable packaging systems are discussed in this section.

5.1. Shipping Cost

The shipping costs of recyclable, disposable, and reusable packaging systems:

1. Shipping cost for recyclable packaging system $(\mathrm{SC})_{\mathrm{re}}$:

$$(\mathrm{SC})_{\mathrm{re}} = \sum_{i=1}^{m} (N_i \times T_{\mathrm{i}})TR + \sum_{i=1}^{m} (N_r \times T_r)TR$$

Where, $N_i = \sum_{\mathrm{j}=1}^{\mathrm{n}} \sum_{\mathrm{k}=1}^{\mathrm{p}} \sum_{\mathrm{l}=1}^{\mathrm{q}} \left\{ \frac{Prod \times nu_j / PC_{jk}}{TC_{kl}} \right\}$

2. Shipping cost for disposable packaging system $(\mathrm{SC})_{\mathrm{d}}$:

$$(\mathrm{SC})_{\mathrm{d}} = \sum_{i=1}^{m} (N_i \times T_{\mathrm{i}})TR + \sum_{i=1}^{m} (N_d \times T_d)TR$$

3. Shipping cost for reusable packaging system $(\mathrm{SC})_{\mathrm{ru}}$:

$$(\mathrm{SC})_{\mathrm{ru}} = \sum_{i=1}^{m} (N_i \times T_{\mathrm{i}})TR + \sum_{i=1}^{m} (CR_{ru} N_i \times T_i)TR$$

These equations show the relationship between shipping cost and shipping cost variables. It illustrates that the number of trips from supplier to manufacturer is the function of production volume, number of parts required per product, and packages capacity. But, the values of number of parts required per product and capacity of packages are fixed for products. Similarly, the collapsible ratio of package is packaging design parameters and standard for individual package. The truck capacity is constant for any given truck size and transportation rate is not under control of a manufacturer or supplier. Hence, for or sensitivity analysis we are keeping all these variables constant.

On the other hand, number of trips from suppliers to manufacturer, distance between suppliers and manufacturer, distance between the manufacturer and a recycling center, and distance between the manufacturer and disposal landfill has direct influence on the shipping cost.

Hence, shipping cost of recyclable, disposable, and reusable packaging systems is functions of:

1. Number of trips from supplier to manufacturer (Ni)
2. Distance between suppliers and manufacturer (T_i)
3. Distance between manufacturer and recycling center (T_r)
4. Distance between manufacturer and disposal landfill (T_d)

For sensitivity analysis, we considered the scenario with a single supplier and manufacturer. The distance from supplier to manufacturer and number of trips from supplier to manufacturer are taken as the averages from the Toyota case study. A single package size is considered in analysis with dimension equal to average container size used in Toyota case study. Standard 20 foot trucks are considered for shipping of packages from supplier to manufacturer and manufacturer to a recycling center or disposal landfill. Therefore, for considered scenario of a single supplier and manufacturer the values of suffix i=k=l=1.

The shipping cost of recyclable, disposable and reusable packaging systems with a single supplier and manufacturer is:

Shipping cost of recyclable packaging system:

$$SC_{re} = \{(N_1 \times T_1) + (CR_{re} \times N_1 \times T_r)\} \times TR$$

Shipping cost of disposable packaging system:

$$SC_d = \{(N_1 \times T_1) + (CR_d \times N_1 \times T_d)\} \times TR$$

Shipping cost of reusable packaging system:

$$SC_{ru} = \{(N_1 \times T_1) + (CR_{ru} \times N_1 \times T_1)\} \times TR$$

5.2. Labor Cost

The labor cost of recyclable, disposable, and reusable packaging systems with a single supplier and manufacturer is:

Labor costs for recyclable packaging system:

$$(LC)_{re} = \{(N_1 X\ LT) + (N_1\ X\ ULT) + (CR_{re}\ X\ N_1\ X\ LT)\} X\ LR$$

Labor costs for disposable packaging system:

$$(LC)_d = \{(N_1 X\ LT) + (N_1\ X\ ULT) + (CR_d\ X\ N_1\ X\ LT)\} X\ LR$$

Labor cost of reusable packaging system:

$$(LC)_{ru} = \{(N_1 X\ LT) + (N_1\ X\ ULT) + (CR_{ru}\ X\ N_1\ X\ LT)\} X\ LR$$

These equations show that the labor cost depends upon collapsible ratio of packages, the number of trips from supplier to manufacturer, loading time, unloading time, and labor rate. As already discussed in the previous section, collapsible ratios, loading time, and unloading time are considered as constant. The labor rate is an external factor and not under the control of manufacturer or supplier. Therefore, number of trips from supplier to manufacturer is the only variable which influences on labor cost.

5.3. Packaging Material Cost

The packaging material cost of recyclable, disposable, and reusable packaging systems with a single supplier and manufacturer is:

Packaging material cost for recyclable packaging system:

$$(PMC)_{re} = (REP_1 \times REPC_1) \ = N_1 \times TC \ \times REPC_1$$

Packaging material cost for disposable packaging system:

$$(PMC)_d = (DP_1 \times DPC_1) = N_1 \times TC \ \times DPC_1$$

For sensitivity analysis we are considering standard truck size having fixed capacity of a single size packages. Therefore, the material packaging cost of recyclable and disposable packaging systems is function of number of trips from supplier to manufacturer and unit cost of reusable and disposable packages.

The packaging material cost for reusable packaging system with a single supplier and manufacturer is:

$$(PMC)_{ru} = (RUP_1 \times RUPC_1)$$

Where, RUP_1 = Number of reusable packages in the system

$RUPC_1$= Average price of reusable packages

The number of reusable packages for single supplier and manufacturer can be written as:

$$RUP_1 = \frac{N1 \ X \ TC_{11}}{(365/DT)} + SS$$

Where DT =Average dwell time

In the above equation $\frac{N1 \ X \ TC_{11}}{(365/DT)}$ is the minimum number of reusable packages require and SS is safety stock.

$$(PMC)_{ru} = \left\{\frac{N1\ X\ TC_{11}}{(365/DT)} + SS\right\} \times RUPC_1$$

The above equation shows that the packaging material cost for reusable packaging system depends upon the number of packages in the system and the average cost of reusable packages. The number of packages in the system is a function of number of trips from suppliers to manufacturer and average dwell time.

Hence, the packaging material cost of recyclable, disposable, and reusable packaging systems is depends upon:

1. Number of trips from supplier to manufacturer
2. Average cost of reusable packages
3. Average dwell time of reusable packages (only for recyclable packaging system)

5.4. Product Damage Cost

Product damage of recyclable, disposable, and reusable packaging systems with a single supplier and manufacturer is:

Product damage cost for recyclable packaging system:

$$(PDC)_{re} = (PDF)_{re} \times \ (REP_1 \times \ REMP_1)$$

Where, $REP_1 = N1 \times TC$

$REMP_1 =$Average cost of products inside recyclable package.

Product damage cost for disposable packaging system:

$$(PDC)_d = (PDF)_d \times \ (DP_1 \times \ DMP_1)$$

Where, $DP_1 = N1 \times TC$

$DMP_1 =$ Average cost of products inside disposable package.

Product damage cost for reusable packaging system:

$$(PDC)_{ru} = (PDF)_{ru} \times \ (RUPT_1 \times \ RUMP_1)$$

Where, $RUPT_1$ = Number of turns of reusable packages.

$= N1 \times TC$

$RUMP_1$ = Average cost of product inside reusable package.

The equations show that product damage cost depends upon product damage frequency and number of trips from supplier to manufacturer. As identical packages are used for recyclable, disposable, and reusable packaging systems the average cost of material inside packages is the same.

5.5. Recycling Cost

The recycling cost of recyclable and reusable packaging systems with a single supplier and manufacturer is:

Recycling cost of recyclable packaging system:

$$RC_{re} = RR \ \times (REP_1 \times \ REW_1)$$

Recycling cost of reusable packaging system:

$$RC_{ru} = RR \ \times (RUP_1 \times \ RUW_1)$$

The equations show that recycling cost depends upon rate of recycling, number of packages transported and average weight of package. The number of packages transported per unit time is a function of the number of trips from supplier to manufacturer and number of reusable packages in the system. Hence, the factors which affecting recycling cost are: number of trips from supplier to manufacturer, recycling rate, and number of reusable packages in the system.

5.6. Disposal Cost

The disposal cost of recyclable and reusable packaging systems with a single supplier and manufacturer is:

Disposal cost of disposable packaging system:

$DC_d = DR \times (DP_1 \times DW_1)$

Disposal cost of reusable packaging system:

$DC_{ru} = DR \times (RUP_1 \times RUW_1)$

Similar to recycling cost the variables which affect disposal costs are number of trips from supplier to manufacturer, disposal rate, and number of disposable packages in the system.

5.7. Maintenance Cost

Maintenance cost is applicable only for a reusable packaging system. The maintenance cost of reusable packaging system with a single supplier and manufacturer is:

$MC = \theta \times (PMC)_{ru}$

The equation shows that the maintenance cost is the fraction of the material cost considered for maintenance. The packaging material cost is already discussed in the previous section therefore fraction of the reusable material cost is the only variable considered which affect the maintenance cost.

The list of variables which influence total cost of recyclable, disposable, and reusable packaging system is shown in Table 5.1. It shows that the number of trips from supplier to manufacturer is the common variable which affects all cost factors. The terms which are assumed as constant for sensitivity analysis are shown in Appendix A.3. The range of variables considered for sensitivity analysis is shown in Table 5.2.

Table 5.1. List of cost variables which influences total cost of packaging systems

	Packaging System Alternatives		
	Expendable Packaging		Reusable Packaging
Associated Costs	Recyclable	Disposable	
Shipping Cost (SC)	Ni, T_i, T_r	Ni, Ti, T_d	Ni, Ti
Labor Cost (LC)	Ni	Ni	Ni
Packaging Material Cost (PMC)	Ni, REPC	Ni, DPC	Ni, RUPC, DT
Product Damage Cost (PDC)	Ni, PDF_{re}	Ni, PDF_d	Ni, PDF_{ru}
Recycling Cost (RC)	Ni, RR	NA	RR, RUP_k
Disposal Cost (DC)	NA	Ni DR	DR, RUP_k
Maintenance Cost (MC)	NA	NA	θ

Table 5.2. Variables range considered for sensitivity analysis

Description	Minimum	Maximum	Average Toyota
Number of trips from supplier to manufacturer	50	5,000	400
Distance between supplier to manufacturer (miles)	20	4,000	190
Distance between manufacturer and recycling center (miles)	20	2,000	100
Distance between manufacturer and disposal landfill (miles)	20	2,000	100
Product damage frequency of expendable packages (percentage)	0.5%	8%	2.5%
Product damage frequency of reusable packages (percentage)	0.5%	8%	2.0%
Maintenance cost as a percentage of material cost	0.5%	8%	5.0%
Average dwell time (days)	1	30	5
Life of reusable packages (years)	1	10	3

The variables considered for sensitivity analysis includes:

1. The number of trips from supplier to manufacturer (N_i)

   This is the most important variable which influences almost all cost factors. This analysis illustrates the impact of number of trips from supplier to manufacturer on total cost of recyclable, disposable, and reusable packaging systems. For sensitivity analysis, we considered the number of trips from supplier to manufacturer from 50 trucks to 5,000 trucks per year. The observations regarding the performance of various cost factors for number of trips from supplier to manufacturer are:

   i. The shipping cost of recyclable, disposable, and reusable packaging systems for different values of number of trips from supplier to manufacturer is shown in Figure 5.1. It shows that the shipping cost of recyclable and disposable packaging systems is the same and less than a reusable packaging system. The difference between shipping cost of expendable packaging system (recyclable and disposable) and reusable packaging system is very small for less number of trips from supplier to manufacturer. However, as the number of trips increases the difference between shipping cost of expendable and reusable packaging systems is very high. From this we can say that if the criterion of selection of packaging system is minimum shipping cost then recyclable or disposable packaging system will be first choice.

   ii. The labor cost of all three types of packaging systems for different number of trips from supplier to manufacturer is shown in Figure 5.2. It shows that the labor cost of all packaging systems is almost the same for fixed number of trips from supplier to manufacturer.

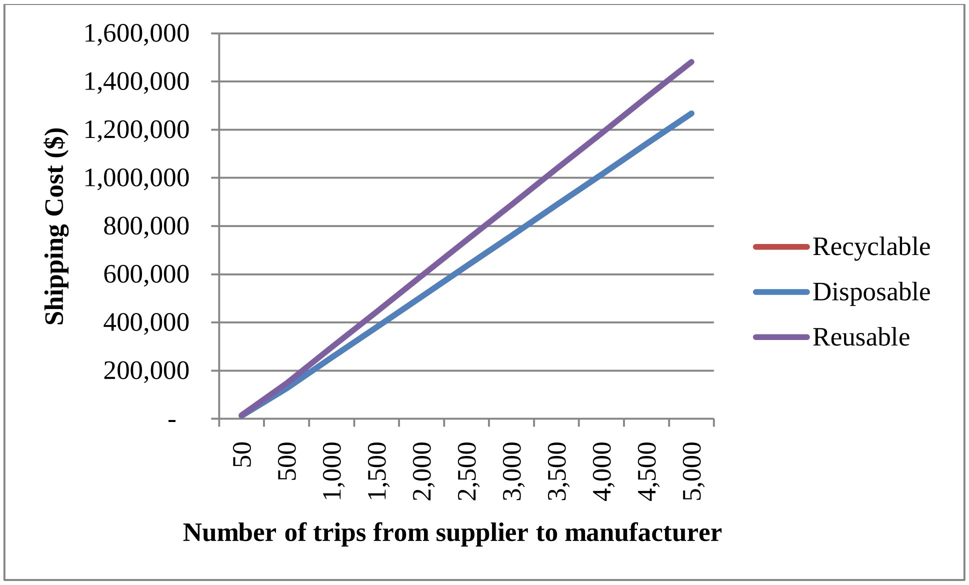

Figure 5.1. The impact of number of trips from supplier to manufacturer on shipping cost

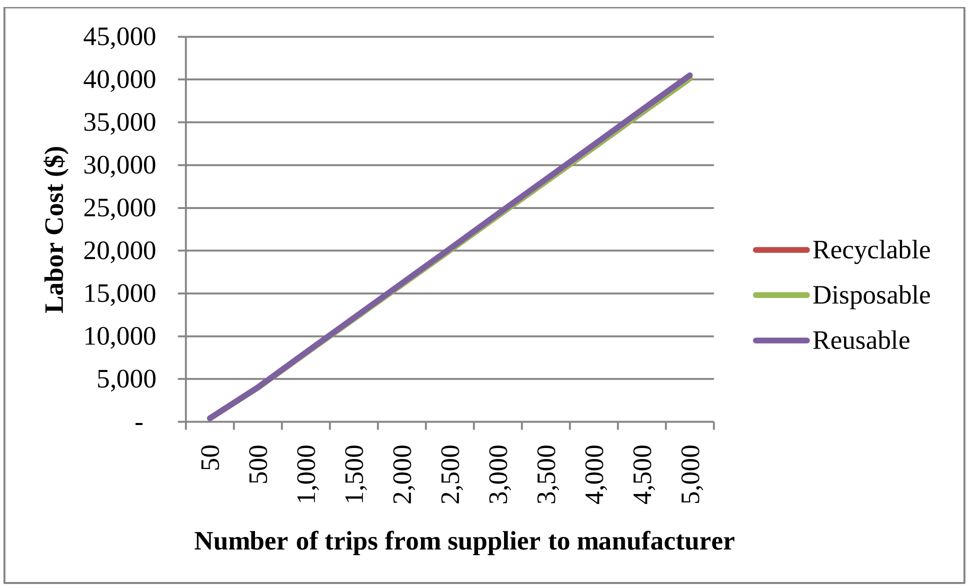

Figure 5.2. The impact of number of trips from supplier to manufacturer on labor cost

iii. The packaging material cost of all three packaging systems for different number of trips from supplier to manufacturer is shown in Figure 5.3. The packaging material cost of recyclable and disposable packaging systems is the same as identical packages are used for both packaging systems. The packaging material cost of a recyclable packaging system depends on the life of packages. In sensitivity analysis we considered the life of reusable packages as 3 years for which the packaging material cost of reusable packaging system is less than recyclable and disposable packaging systems.

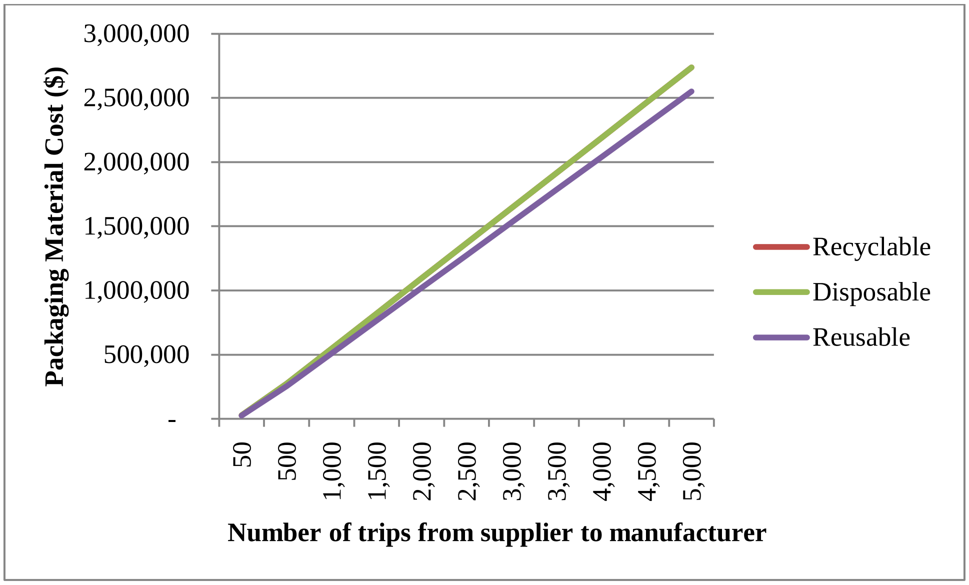

Figure 5.3. The impact of number of trips from supplier to manufacturer on packaging material cost

iv. The product damage cost of recyclable, disposable, and reusable packaging systems for different number of trips from supplier to manufacturer is shown in Figure 5.4. It shows that the product damage cost of reusable packaging system is less than the recyclable and disposable packaging systems.

v. The recycling, disposal, and maintenance cost of recyclable, disposable, and reusable packaging systems respectively are shown in Figure 5.5. In the case of recyclable packaging system, the manufacturer get revenue for recycling of packages which helps to reduce overall cost of recyclable packaging system. On the other hand, disposal and maintenance cost increase total cost of the disposable and reusable packaging systems respectively.

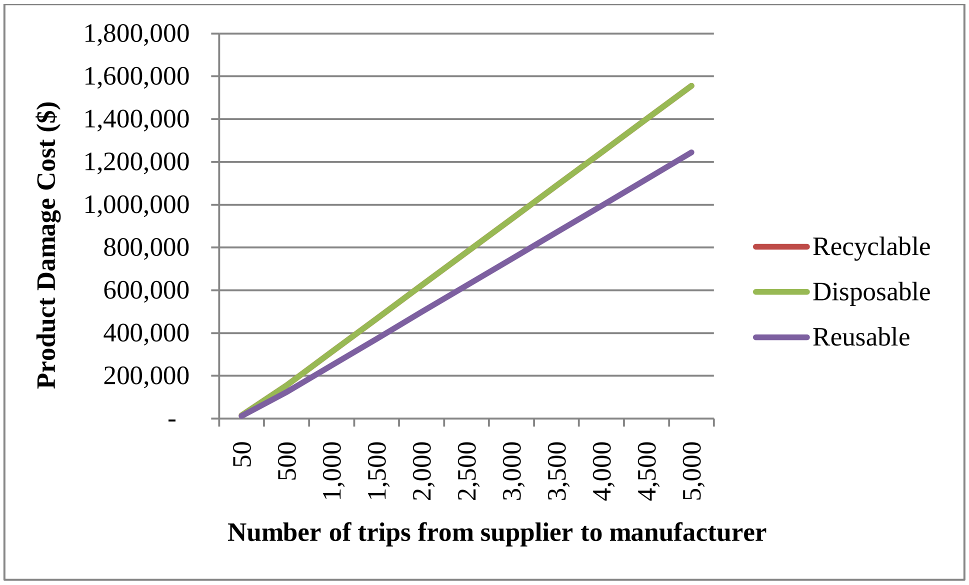

Figure 5.4. The impact of number of trips from supplier to manufacturer on product damage cost

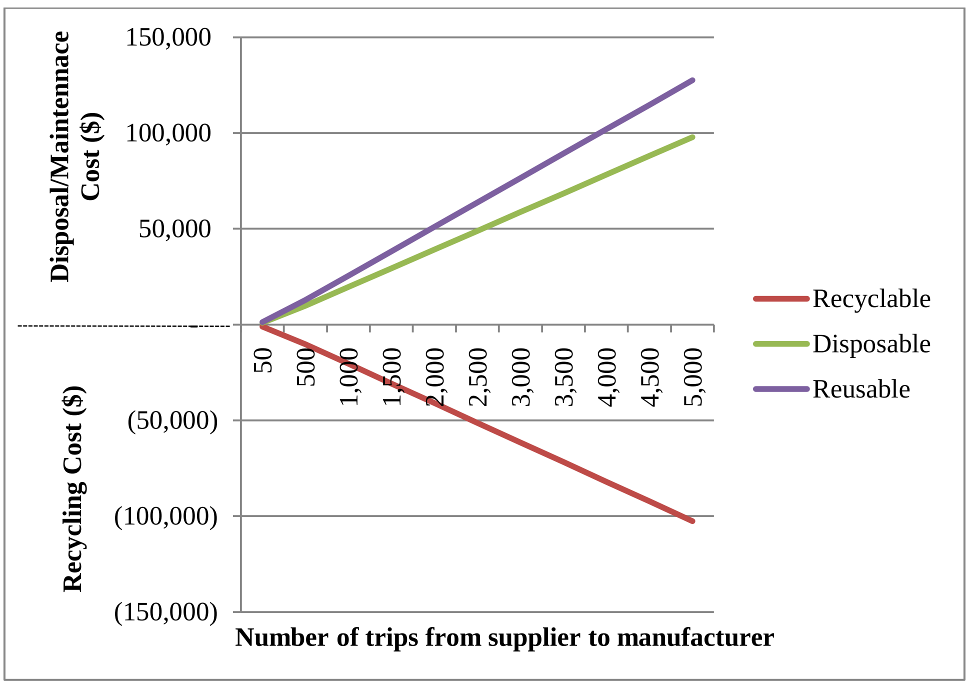

Figure 5.5. The impact of number of trips from supplier to manufacturer on recycling, disposal, and maintenance cost

The comparison of total cost of all three packaging systems for different number of trips from supplier to manufacturer is shown in Figure 5.6. It shows that the total cost of a reusable packaging system is less than recyclable and disposable packaging systems. The recyclable packaging system requires next higher cost and disposable packaging system is the most expensive packaging option.

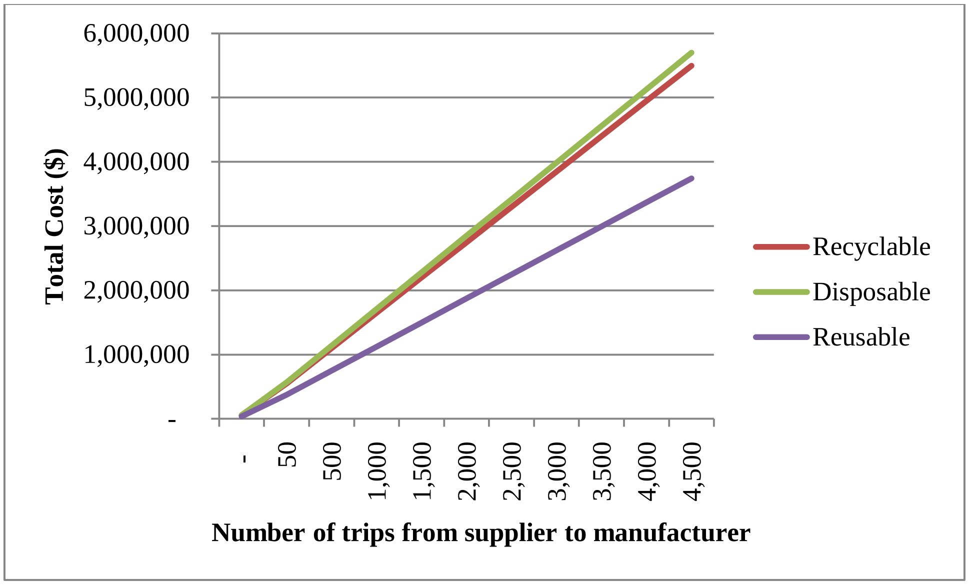

Figure 5.6. The impact of number of trips from supplier to manufacturer on total cost

2. Distance from supplier to manufacturer (Ti)

Another variable which influences total cost of recyclable, disposable, and reusable packaging systems is the distance between supplier and manufacturer. For sensitivity analysis, we considered the average distance between supplier and manufacturer from 20 miles to 4,000 miles. The impact of change of distance from supplier to manufacturer on total cost of recyclable disposable, and reusable packaging systems is as shown in Figure 5.7.

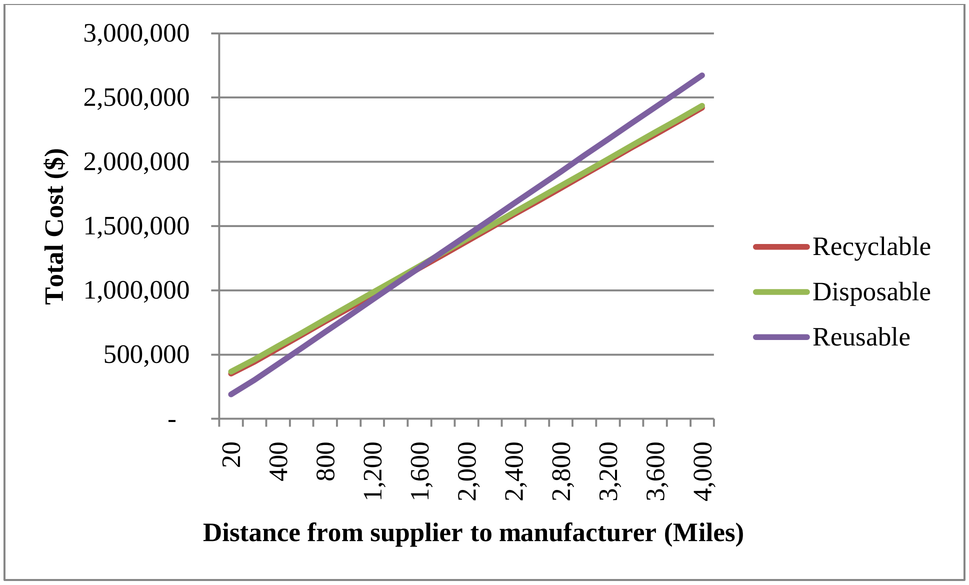

Figure 5.7. The impact of distance from suppliers to manufacturer on total cost

It illustrates that for short distances from supplier to manufacturer a reusable packaging system is the most economical option. As distance from supplier to manufacturer increases there is a tradeoff between total cost of reusable and recyclable packaging systems. Further increases in the distance between supplier and manufacturer result in another tradeoff between total cost of reusable and disposable packaging systems. Hence, for short distances between supplier and manufacturer, recyclable packaging system is the most economic packaging option. On the other hand, for long distances between supplier and manufacturer, the recyclable packaging system is the most economical packaging option.

3. Distance from manufacturer to recycling center (T_r)

The distance from a manufacturer to a recycling center affects the total cost of recyclable packaging system. The impact of different values of distance between a manufacturer and a recycling center on total cost of recyclable packaging system and its comparison with disposable and reusable packaging systems is shown in Figure 5.8.

It shows that, as the distance from manufacturer to recycling center increases, there is a tradeoff between total cost of recyclable and disposable packaging systems. But, a reusable packaging system is always an economical option for all distances between manufacturer and recycling center.

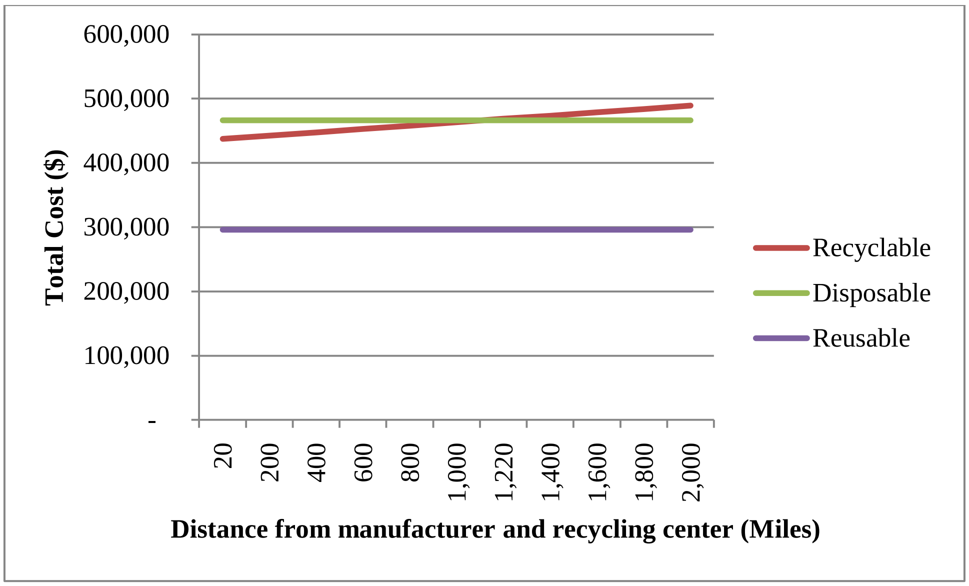

Figure 5.8. The impact of distance from manufacturer and recycling center on total cost

4. Distance from manufacturer to disposal Landfill (T_d)

The distance from manufacturer to disposal landfill influences only shipping cost of disposable packaging system. The impact of different values for the distance parameter between manufacturer and disposal landfill on total cost of disposable packaging system and the comparison with recyclable and reusable packaging systems are shown in Figure 5.9. It shows that the total cost of disposable packaging system is always more than recyclable and reusable packaging systems and there is no effect on decision of the economical packaging system.

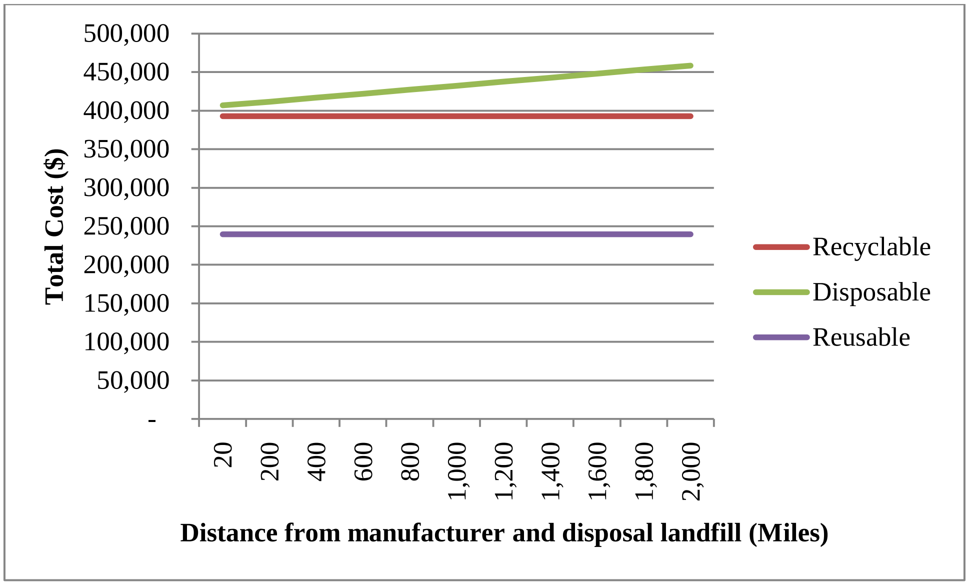

Figure 5.9. The impact of distance from manufacturer to disposal landfill on total cost

5. Average dwell time (DT)

Total cost of reusable packaging system for different values of average dwell time and its comparison with total cost of recyclable and disposable packaging systems is shown in Figure 5.10. The figure shows that for a shorter dwell time the total cost of reusable packaging system is least and it is the most economical packaging option. Dwell time increases results in first tradeoff between total cost of reusable and recyclable packaging systems followed by second tradeoff between total cost of reusable and disposable packaging systems. This suggest that for the shorter dwell time reusable packaging is the most economical option and for longer dwell time recyclable packaging is the most economical packaging option.

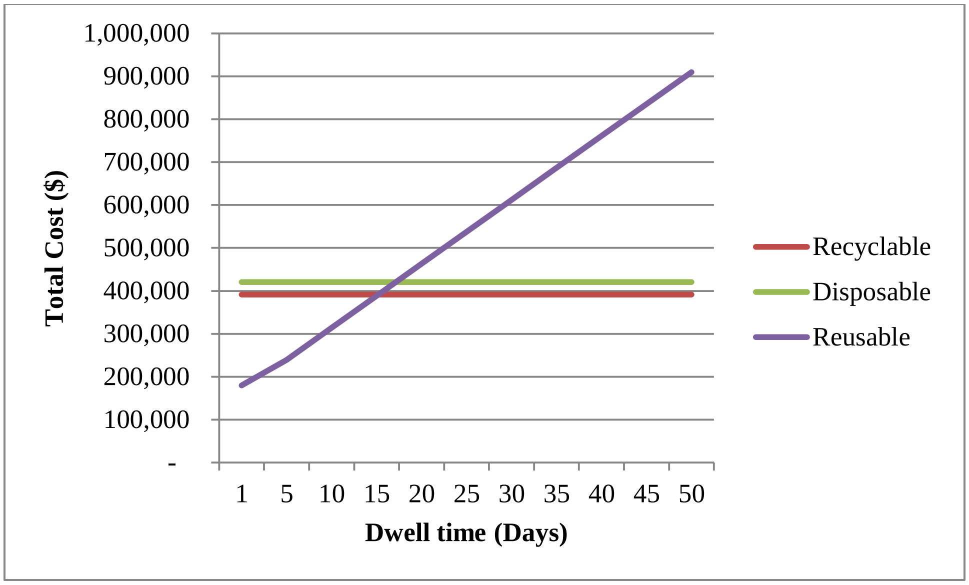

Figure 5.10. The impact of dwell time on total cost

6. Product damage frequency of recyclable (PDF_{re}), disposable (PDF_d), and reusable packaging (PDF_{ru}) systems

The product damage frequency influences on product damage cost. The product damage frequency of recyclable and disposable packaging systems is the same as identical packages are used for recyclable and disposable packaging systems. The total cost of recyclable and disposable packaging systems for different values of product damage frequency and its comparison with total cost of a reusable packaging system are shown in Figure 5.11. It shows that for all values of product damage frequency of the recyclable and disposable packaging systems the total cost of reusable packaging system is always the least.

Similarly, Figure 5.12 shows total cost of a reusable packaging system for different values of product damage frequency and its comparison with total cost of recyclable and disposable packaging systems. For small values of product damage frequency the total cost of reusable packaging system is less than the recyclable and disposable packaging systems. As damage frequency of reusable packages increases there is a tradeoff between total cost of reusable and recyclable packaging systems. Further increase in damage frequency of reusable packaging system shows that total cost of reusable packaging system is higher than the disposable packaging system.

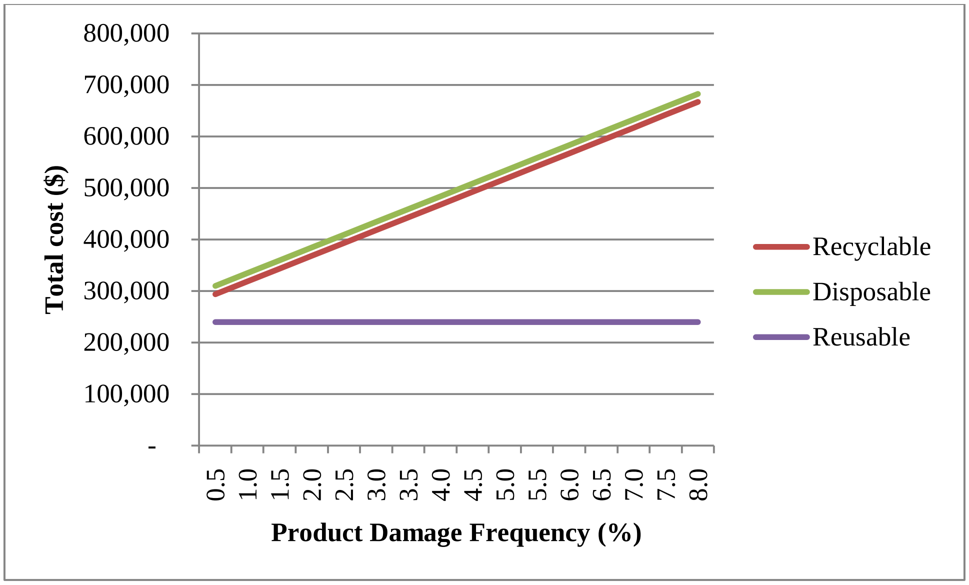

Figure 5.11. The impact of product damage frequency of recyclable and disposable packaging systems on total cost

The damage frequencies of recyclable, disposable and reusable packaging systems are considered to be 0.02, 0.025 and 0.025 respectively. The damage frequency of reusable packaging system is always less than recyclable and disposable packaging systems. Therefore, product damage cost of reusable packaging system is always less than the recyclable and disposable packaging systems.

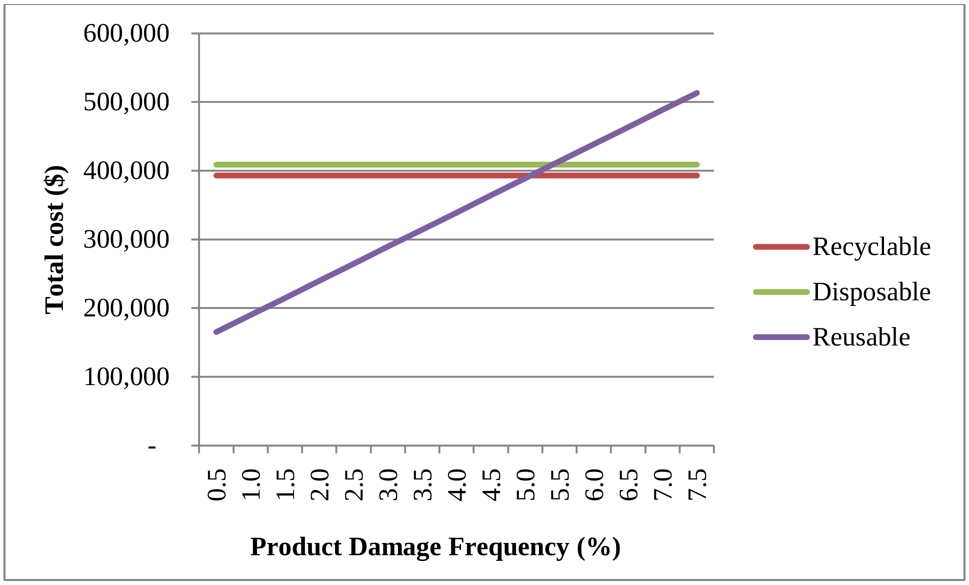

Figure 5.12. The impact of product damage frequency of reusable packaging system on total cost

7. Recycling rate (RR), disposal rate (DR) and maintenance cost fraction (MC)

    The impact of change of recycling rate, disposal rate, and maintenance factor on total cost of recyclable, disposable and reusable packaging systems is shown in Figure 5.13, Figure 5.14 and Figure 5.15 respectively. The figures illustrate that for any given values of recycling rate, disposal rate, and maintenance factor there is no effect on the decision of the economical packaging system as these costs are very small compare to other cost of all packaging systems. In all three cases, the total cost of reusable packaging system is always less and followed by recyclable packaging system.

8. Life of reusable package (L)

    The total cost of reusable packaging system for different values of package life and its comparison with recyclable and disposable packaging systems are shown in Figure 5.16. The figure shows that the total cost of reusable packaging system decreases when the life of reusable packages increases. Initially, with small changes in recyclable packages life there is a noticeable change in total cost of reusable packaging system. Eventually a point is reached where improved package life has less noticeable change in total cost of reusable packaging system.

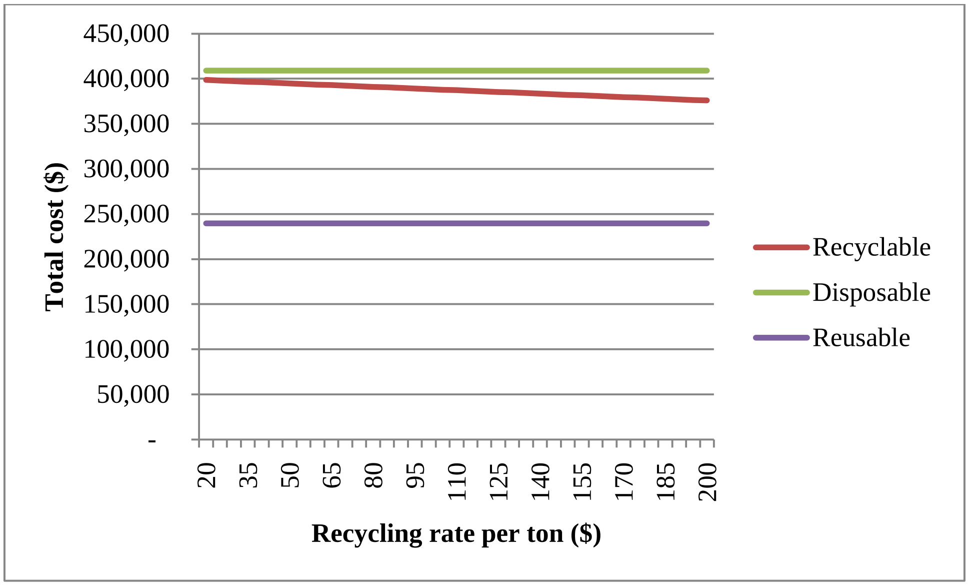

Figure 5.13. The impact of recycling rate on total cost

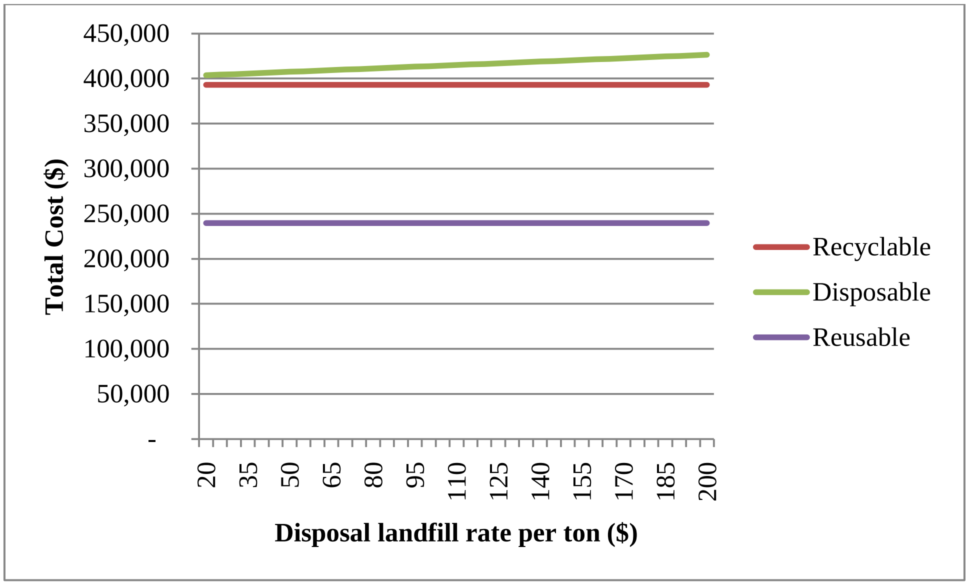

Figure 5.14. The impact of disposal landfill rate on total cost

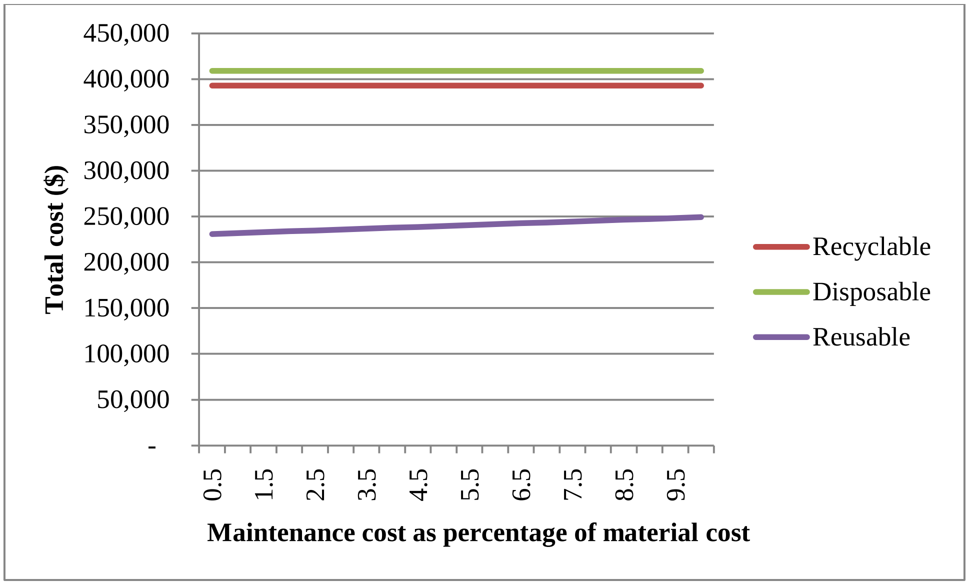

Figure 5.15. The impact of maintenance cost on total cost

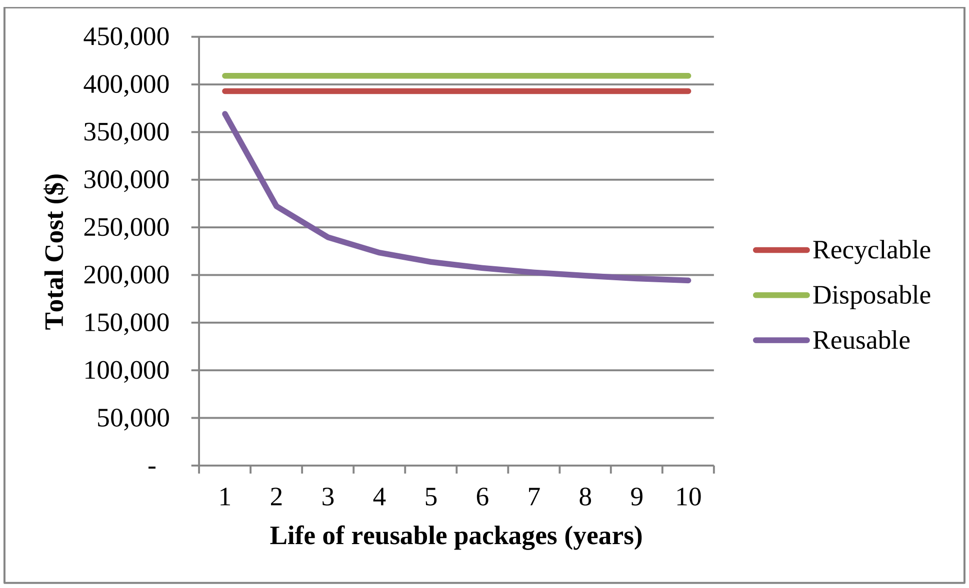

Figure 5.16. The impact of life of reusable packages on total cost

CHAPTER 6. CONCLUSIONS AND FUTURE RESEARCH

6.1. Conclusions

In this research, we identify significant cost factors which influence recyclable, disposable, and reusable packaging systems by comprehensive cost study and analysis. Some new factors such as the collapsible ratio of recyclable, disposable and reusable packaging systems are included in the cost analysis that help for better estimation. The proposed model can be used for conducting economic analysis of packaging systems across different industries and configurations. The developed model is verified by comparing with an earlier research based on the Toyota case study.

By conducting sensitivity analysis, we conclude that some cost factor has a large contribution in total cost of packaging systems. The product damage cost has the highest contribution in total cost of all types of packaging systems. On the other hand, recycling revenue, disposal cost, and maintenance cost have least contribution in all types of packaging systems. The labor cost of all types of packaging systems is almost the same.

In sensitivity analysis, we identify important factors which influence the most for the decision of an economical packaging system. Alternatively, there are various factors which least influence in procedure of selection of an economical packaging system.

The factors which play the most significant role in determining the economical packaging system are:

- Distance between supplier to manufacturer
- Dwell Time
- Product damage frequency of reusable packages

- Life of reusable packages
- Production volume

The factors that not significantly influence the decision of packaging system are:

- Labor Cost
- Distance from manufacturer to recycling center
- Distance from manufacturer to disposal landfill
- Recycling rate
- Disposal rate

In conclusion, for an economic analysis of recyclable, disposable, and reusable packaging systems it is not necessary to consider all factors. Concentrating on the most significant factors might simplify the cost analysis.

6.2. Future Research

There are several areas in which research can be extended. Some of the suggestions for future research are:

- This model is developed to help with economic packaging system which is only based on total cost of packaging system. There are several other criteria to select packaging system such as environmental benefits. Further research can be conducted to consider the environmental benefits of various packaging systems or establishing tradeoff between environmental benefits and economic benefits.
- In this research, we assume that suppliers send materials to a single manufacturer but in reality, suppliers send materials to several manufacturers. Hence, the additional path for the research is to study the case in which

suppliers sends materials to multiple manufacturers and identifies effect of this on supply chain.

- This research is based on deterministic demand; the models based on the stochastic demand might also be developed.
- The tracking system benefits of reusable packaging system are not considered in this research. The research can be extended by considering the benefits of tracking system in reusable packaging and establishing related cost analysis.

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APPENDIX

Table A.1. Supplier information of Toyota Motor Manufacturing Indiana Inc (TMMI) (Goldsby et al., 2000)

Supplier	Location (Mileage)	Parts Supplied	Pieces/ Truck	Container Type	Pieces/ Container	Dwell Time
Blue grass Industries	Lexington KY (192)	Shocks	4	3	8	5.5
		Steering column	1	3	5	5.75
		Steering wheel	1	3	5	5.75
		Lug nuts	24	1	100	5.5
Blue Inc.	St. Louis MO (174)	Stereo system	1	3	8	6.5
		Stereo speakers	4	4	12	5.5
Kentucky Industries	Frankfort KY (170)	Instrument panel molding	1	1	50	7.5
		Interior quarter trim	2	2	6	5.5
		Interior door handles	2	2	12	6.5
		Exterior door mirror	2	3	6	6.5
		Interior rearview mirror	1	3	32	7.5
Missouri Industries	Fenton MO (195)	Over-fender plastic	4	4	12	5.5
		Glove box	1	4	4	5.5
		Center console	1	3	4	5.5
		Fuel tank protector	1	3	20	6.5
		Fuel tank cap	1	2	12	6.5
Reeds Inc.	Cincinnati OH (223)	Front grill	1	4	5	5.75
		Passenger side airbag	1	3	4	5.5
		Shoulder-strap seatbelts	2	2	6	5.5

Table A.2. Shipping packaging comparison (Goldsby et al., 2000)

		Weight (lbs)		Cost per Unit		Damage Frequency	
Container Type	Dimension	Expend.	Return.	Expend.	Return.	Expend.	Return.
1	12 x 15 x 7”	0.61	2.8	$0.29	$29.49	2.5	2
2	24 x 15 x 7”	0.82	4.37	0.49	44.88	2.5	2
3	24 x 22 x 11”	0.95	6.18	0.66	52.65	2.5	2
4	48 x 22 x 15”	1.68	12.2	2.07	99.69	2.5	2

Note: Expend. = Expendable and Return. = Returnable

Table A.3. System input parameters (Goldsby et al., 2000)

Description	Symbol	Value
Production volume (per year)	Prod	102,000
Distance between supplier to manufacturer (miles)	Ti	Table A.1
Transportation rate (per mile)	TR	1.3
Life of reusable packaging (years)	L	3
Loading time (hours)	LT	0.5
Average labor rate (per hour)	LR	$15
Dwell time (days)	DT	Table A.1
Average reusable and disposable package cost (per unit)	$REPC_{=}$ DPC	Table A.2
Average reusable packaging cost (per unit)	$RUPC_k$	Table A.2
Safety stock for reusable packaging	SS	5%
Damage frequency for recyclable and disposable packages	$PDF_{re} = PDF_d$	0.025
Damage frequency for reusable packaging	PDF_{ru}	0.02
Average cost of material inside recyclable and disposable packages	REMP= DMP	$100.00
Average cost of material inside unit reusable package	RUMP	$100.00
Average revenue from recycling per ton	RR	$65.00
Average disposal cost per ton	DR	$62.00

Table A.4. Additional input parameters

Description	Symbol	Value
Distance between manufacturer and recycling center	T_r	100
Distance between manufacturer and disposal landfill	T_d	100
Collapsible ratio of recyclable and disposable packages	$CR_{re} = CR_d$	0.05
Collapsible ratio of reusable packaging	CR_{ru}	0.2
Average time required for unloading the truck	ULT	0.5
Maintenance cost as a percentage of material cost	θ	0.05